Public Perceptions of Alternative Silvicultural Treatments

Gordon A. Bradley[1]

ABSTRACT

Visual impacts of alternative timber harvest practices are important to consider when developing timber harvest plans or undertaking ecosystem management operations. People's reaction to alternative timber management practices may be related to their level of confidence in the stewardship capabilities of forest management organizations. Determining visual preferences for alternative timber harvest practices is one way of identifying the visual effects of alternative patterns. Ongoing work at the Capitol State Forest, located near Olympia, Washington, has provided a comprehensive look at visual preferences for six alternative harvest patterns by various interest groups. These groups include foresters, recreationists, environmentalists, educators, and the general public. Groups tend to share a common preference for patterns showing minimal disturbance but are significantly different as the intensity of harvest practices increase. Foresters showed higher preferences for intensive forest management practices, whereas all other groups indicated a lower preference for intensive forest practices. Tree retention, harvest size, and residual material seem to be contributing factors related to preference ratings.

KEYWORDS: Visual resource management, public perceptions.

INTRODUCTION

This paper reports on a collaborative project between the Washington State Department of Natural Resources (DNR) and the USDA Forest Service, Pacific Northwest Research Station (PNW), in cooperation with the University of Washington College of Forest Resources (UW). The collaborators are conducting a joint study of the silvicultural, economic, and visual effects of alternative timber harvest patterns at the Capitol State Forest near Olympia, Washington. The public perception or visual effects aspect of the study explores how various visual cues affect public responses to alternative timber harvesting patterns.

To obtain as much information as possible at a reasonable cost, color photographs of sites were used to survey people's reactions to alternative forest harvest patterns and the visual and cognitive cues within them. Photos have been found suitable for comparing the visual attractiveness or suitability of landscapes (Brown and Daniel 1984, Kaplan and Kaplan 1989). They also are cost effective. This study captures foreground, middle, and background views.

PREVIOUS FINDINGS

In the context of forest aesthetics, research studies on visual preference generally show that people agree on what makes for an aesthetically pleasing landscape and which modifications create negative visual impacts. Overall, people tend to prefer landscapes that retain more standing green trees and that minimize the amount of residual material such as stumps and brush (Brown and Daniel 1984, Ribe 1989). Many studies have found that a sense of order is preferred in the landscape as indicated by high ratings for park-like settings, large trees, and landscapes that appear "natural." Ground cover and a mix of vegetation are generally preferred over bare soil and a uniform stand of trees (Bacon 1995, British Columbia Ministry of Forests 1981

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and 1994, Brown and Daniel 1984, Ribe 1989, Ulrich 1986). The time since initial harvest is also an important factor in determining visual preference. Over time, preference ratings improve for sites that have been intensively managed, and the differences among sites with various silvicultural treatments diminish (Shelby et al. 2003). For many people, preferences for forest scenes rise and fall in a similar pattern, but preferences for certain scenes may differ based on their relationship with the landscape. The findings of empirical research have been incorporated into numerous texts, manuals, and guides that are used by various natural resource management agencies and professional organizations (Bradley 1996; Forestry Authority 1994; Lucas 1991; Northeast Regional Agricultural Engineering Service 1993; USDA FS 1974, 1980).

BLUE RIDGE STUDY

Work on the Blue Ridge study began prior to the actual harvest of trees. Prior to harvesting, a complete set of onsite photographs was taken in July 1997 from plot center markers on all plots established by the PNW Research Station, Olympia. After the research plots were harvested, photographs were taken during spring of each subsequent year through 2004.

Photographs were taken at the same location and at the same general time of year to control for seasonal and weather variation in the landscape. Photographs were taken on sunny days in spring, after deciduous trees had leafed out, to minimize the factors that may influence preference ratings such as light angle, fall color, snow, or bare trees. Also, when taking photos, an attempt was made to capture the essence of the scene, avoiding features of the landscape that might otherwise cause a person to give a low rating on the preference survey.

Survey Development

The survey was printed in a 22 by 28 cm (8.5 by 11 in) format with an explanatory letter indicating the purpose of the research and assuring confidentiality for subjects if they responded to the survey. The survey was printed with a postage-paid imprint and return address on the back cover so that when the survey was completed, it could be easily returned to the University of Washington.

The survey contained 30 color photographs depicting the six treatment plots in the study. For each plot, 5 photos representing different views of the treatment and varying amounts of green-up (i.e., time since harvest) were selected. The order of the photos was randomized. For each photo, respondents were asked to indicate how much they liked each scene. A scale of 1 = “not at all,” 3 = “somewhat,” and 5 = “very much” was used for the preference rating. For 10 photographs, representing scenes from each plot, the survey requested additional information regarding why the respondents rated the scene the way they did.

In addition to the photo portion of the survey, respondents completed 4 pages of questions regarding knowledge and attitudes about various aspects of forest management; confidence in different forest management organizations to manage forests; and demographic information including current residence, where he or she grew up, and his or her affiliations with natural resource or environmental organizations

Survey Administration

Selected groups of people were asked to participate in the study. These groups included educators, foresters, environmentalists, recreationists, and the general public. Those sampled in the educator category were identified from a mailing list provided by the Office of the Superintendent of Public Instruction in Olympia. Foresters were sampled from a western Washington Society of American Foresters chapter. Environmentalists were represented by the Sierra Club. Recreationists included individuals from the Issaquah Alps Trails Club and other recreation groups who regularly use Capitol Forest. The Capitol Forest recreation group names were provided by the DNR. Finally, the general public consisted of individuals from both rural and urban addresses in western Washington. Approximately 750 individuals were sent surveys, and 210 responded (about 28 percent). Of those who responded, 32 were urban residents, 18 were rural residents, 55 were foresters, 51 were recreationists, 33 were environmentalists, and 16 were educators (population group for 5 respondents could not be determined). Although the above categories are not mutually exclusive, we stratified the samples by using mailing lists specific to each group.

FINDINGS

In general, foresters tended to show significantly greater preference than most other groups for treatments where tree removal left moderate to large openings (i.e., clearcuts, patch cuts, and group selection); the difference between forester response and other groups was most striking for the clearcut treatment. Most groups tended to show moderate preference for the two-age treatment, with the exception of the environmentalists who showed lower preference. All groups showed high preference for the commercial thin and for the control.

IMPLICATIONS

These findings suggest that preferences are generally similar for different groups of people for most timber harvest practices. There is a significant difference, however, between foresters and all other groups regarding the most intensive timber harvest practices. For example, in this study we found that a forest scene significantly modified by a timber harvest is rated higher by a person working in forestry than by a person who does not work in forestry. This is especially true for clearcutting. When intensive practices are in full view of many people other than foresters, there may be less acceptance of forestry and diminished confidence in the timber industry as sustainable stewards of the land. This lack of confidence can result in diminished support for forestry and may indeed provide the seeds of support for initiatives that further erode discretion of forest managers to practice sustainable forestry. Regulations, guidelines, standards, and lawsuits may all be the result of an increasingly skeptical public.

The management of visual aspects of forestry is one of several important considerations in practicing sustainable forestry. Other considerations include economic and engineering efficiency, worker safety, fish and wildlife habitat, and soil stability. In most cases, visual resource management practices complement these other considerations and are not advocated to be achieved at the expense of other aspects of sustainable forestry. The findings from this study suggest that in visually sensitive landscapes, practices that result in greater tree retention, smaller openings and rapid green-up will reduce the visual impact of timber harvest practices.

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Integrated, Interdisciplinary Forest Research at Solling, Germany—History and Perspectives

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ABSTRACT

The Solling experimental forest is one of the longest, continuously running studies of its kind worldwide. Initially, the scientific approach at the long-term research plots in the mature pure beech (*Fagus silvatica*) and spruce (*Picea abies*) stands was measuring ambient matter and energy transfers at the forest-ecosystem level. Roof experiments were another phase of this forest ecosystem research, comprising experimental manipulation of hydrological and biogeochemical fluxes. In the third phase, a landscape approach was chosen to improve the spatial database for regional forest stands and to integrate ecological and economical information for new concepts of sustainable forest management.

KEYWORDS: Forest ecosystems, long-term research, evolution of methods.

INTRODUCTION

The Solling experimental forest is one of the longest, continuously running studies of its kind worldwide (Ellenberg 1972, Ellenberg et al. 1986, Jansen and Bredemeier 2004). Results from integrated forest ecosystem research conducted in the Solling mountain area in central Germany are widely recognized and have stimulated forest monitoring and research methodology worldwide. The data sets from Solling are, in many cases, unique with respect to the duration of measurements and comprehensiveness of parameters investigated. Research at Solling began almost four decades ago; in the intervening years, ideas, scopes of management, and paradigms have evolved.

We describe the history of integrated experimental forest research at Solling and discuss some of the prominent results. The objective of this historical description is to demonstrate the evolution of ideas and intentions in forest ecosystems research that has occurred over the last 40 years.

LOCATION

Solling is a low mountain range emerging south of the Pleistocene northern German flat plains with elevation ranging from 200 m to 500 m. Some small towns are located in the central mountainous area, and a few small villages are in the interior, but the population density is very low compared to urban and industrial areas in Germany. The forest cover, conversely, is comparatively high, amounting to 60 percent, or 44 000 ha out of 74 000 ha total area.

Solling is a typical "cultural landscape" where the land has been utilized for centuries in many different ways (NFP 1996). Numerous rural settlements established in the medieval period were later abandoned in times of plague and famine and were subsequently covered again by forest. In later times, when the human population grew again and primeval industries emerged, human over-exploitation and livestock degraded the forest in the Solling mountains, and open, over-aged forests or degraded heathlands dominated

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the landscape (Brodhage 1999). In the past two centuries, the forests at Solling and in other parts of Germany regenerated under scientifically based forest management. Many of the forests created by these new methods, however, were often conifer plantations—very different from the primary natural state. This development is typical of many other regions and landscapes in Germany. Forest ecosystem research at Solling started in the early 1960s as part of the International Biological Programme (IBP) when ecosystems representative of the different biomes of the world were selected for investigation (Ellenberg 1972, Ellenberg et al. 1986). A mature pure beech (*Fagus silvatica*) forest on the high Solling plateau at about 500 m elevation was chosen to represent the typical *Luzulo-fagetum* of the temperate humid environment at lower elevations and under naturally oligotrophic site conditions. Shortly after installing the beech site, a neighboring mature Norway spruce (*Picea abies*, ca. 100 years in 1975) plantation forest was equipped in the same manner for comparing measurements.

RESEARCH PHASE 1: MEASUREMENT AND OBSERVATION

Initially, the scientific approach at the long-term research plots in the mature pure beech and spruce stands was measuring ambient matter and energy transfers at the forest-ecosystem level. In the 1960s, when the measurements started, this methodology was absolutely novel. Now, nearly 40 years later, the same methods are used in routine monitoring of forest ecosystems in many countries worldwide, e.g., the European Level-II monitoring network of forests in the International Cooperative Programme

For measurement of liquid phase fluxes, precipitation collectors were installed inside and outside the forest, and porous suction cups or plate lysimeters were embedded in the soil at various depths. Litterfall was sampled and chemically analyzed and repeated soil and humus layer inventories were performed. The combined result of all measurements was a complete input-output budget of all biologically important chemical constituents.

The first results from the biogeochemical flux investigations were a surprise to the scientists at that time. Instead of the expected pristine environmental conditions in a remote forest landscape, the analyses of throughfall and soil solution revealed that these media were highly acidic. Furthermore, when compared to precipitation on open land, a large surplus of acidity and pollutants in throughfall and beech stemflow was detected, indicating a high filtering efficiency of the forest vegetation surfaces for air pollutants. This, in turn, increased the input of these constituents to the forest soil.

A hypothesis was put forward postulating the destabilization of forest ecosystems on naturally poor soil substrates, as in Solling, because of excessive acidification of the soil. This hypothesis was questioned and criticized at first, but during the 1980s, when large-scale forest damage spread over several regions of Germany, it became the basis of extensive research on forest decline.

There was much concern about acid rain and its effects on forests in Germany. This concern led to air pollution legislation, which was quite effective in reducing sulfur inputs (fig. 1).

Nitrogen loads to the forests, however, could not be controlled with the same efficiency (non-point source pollution); they remained comparatively high and thus still contribute to eutrophication of forest soils and waters.

RESEARCH PHASE 2: EXPERIMENTAL ECOSYSTEM MANIPULATION

Roof experiments were another phase of forest ecosystem research, comprising experimental manipulation of hydrological and biogeochemical fluxes. The roof facility at Solling, installed between 1990 and 1991, consists of three roofs, 300 m^2 surface area each, underneath the canopy of a pure Norway spruce stand. The roofs are covered with plates of highly transparent polycarbonate. All throughfall reaching the roof surfaces is collected in a central facility and then redistributed to the plots by a sprinkler system. In a clean rain experiment under one of the roofs, the water is deionized and then resupplied with elements in concentrations representing an average background (preindustrial) throughfall.

A highlight of the results from the Solling roof study was the time-lagged responses of the different ecosystem components to the decreased soil input fluxes brought about by clean rain application (Bredemeier et al. 1998a, Bredemeier et al. 1998b). Soil solution chemistry responded rapidly to decreased input concentrations, particularly in the topsoil where less of the previously stored sulphates are available to counteract the dilution. Decreases in concentrations soon became evident at greater soil depth. Nitrate leaching ceased completely under reduced N-inputs after weeks in the top soil and after several months in the deeper

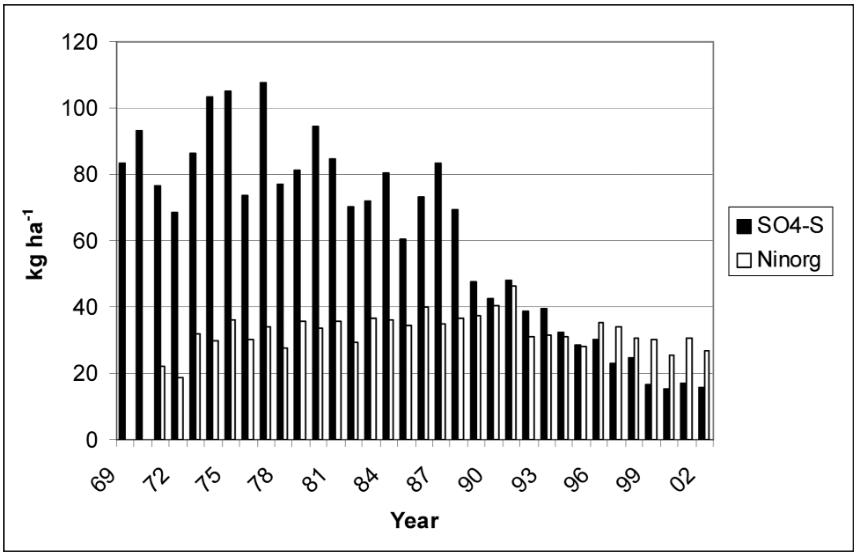

Figure 1—Long-term observation of sulfate-S and inorganic N fluxes in throughfall of an old growth Norway spruce stand (“F1” Solling).

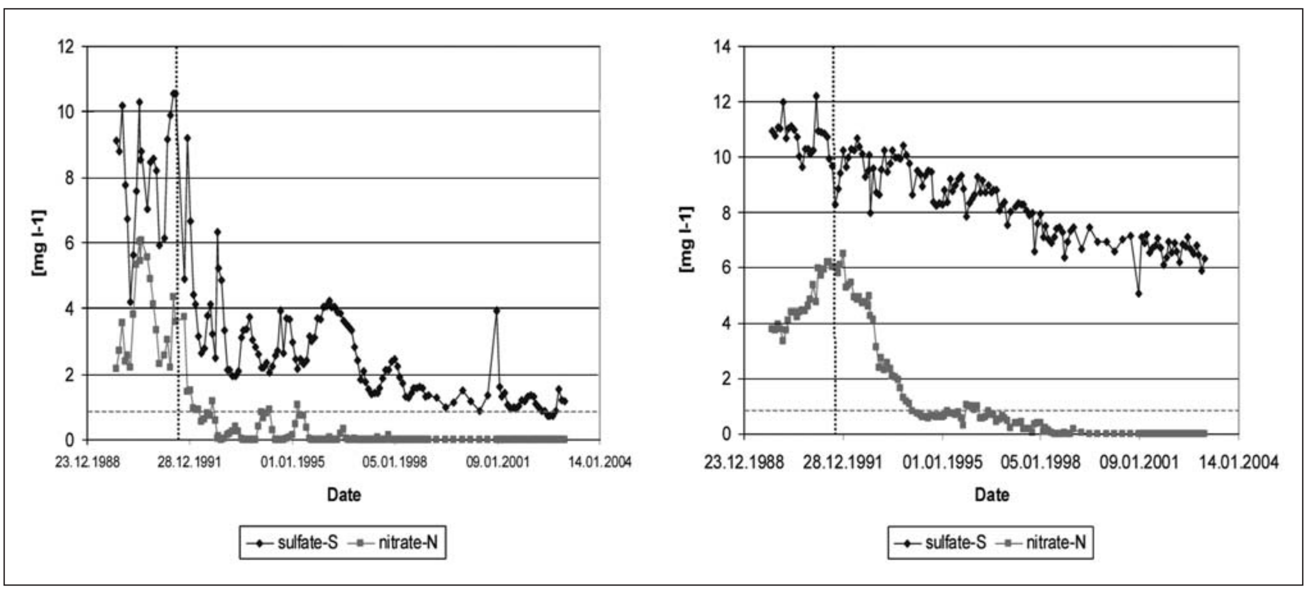

Figure 2—Time courses of sulfate-S and nitrate-N concentrations in 10 cm (left) and 100 cm (right) mineral soil depth of the clean rain roof experiment; vertical reference line indicates start of manipulation, horizontal line nitrate input concentration .

soil (fig. 2). These results demonstrate that nitrate leaching can be efficiently decreased under reduced anthropogenic atmospheric inputs. The soil solution, a nonbiotic equilibrium component, responds fastest, whereas the soil solid phase, due to its high stock of previously stored acidity, changes much more slowly. The fine roots, in intimate contact with the soil water, respond to their changed chemical environment with a time lag, which is a common feature in biological systems. Aboveground physiology and growth are buffered and showed a delayed reaction to these changes in the root zone.

RESEARCH PHASE 3: FROM PLOT-LEVEL PROCESS STUDIES TO LANDSCAPE-LEVEL SCENARIOS AND ASSESSMENTS

Phases 1 and 2 of integrated forest ecosystems research at Solling were mainly plot experiments. Although these were necessary to augment our knowledge about ecosystem processes and the impacts of natural and anthropogenic disturbances, the high levels of effort and investment connected to these investigations allowed the establishment of only a few case studies. The third research phase aims to close the information gap between intensive case studies and "regular," managed forest stands and to develop a link between different spatial scales (Jansen et al. 2004). A landscape approach was chosen to transfer ecological information and to improve the spatial database for regional forest stands.

The outline of the landscape approach was based on two elements: a randomized block design and a grid of 100 m x 100 m covering the whole Solling area. The block design comprised the strata pure beech/mixed beech-spruce/pure spruce stands and young/intermediate/old forest stands. Blocks were chosen in the Solling forest landscape based on geographic information system (GIS) data in such a way that important site conditions (soil type, elevation, slope, etc.) were as homogeneous as possible.

Shift of Scope

In the 1990s, the research focus at Solling shifted from conducting plot studies to applying the newly gained knowledge regarding forest ecosystems on broader scales. The aim was to assign ecological properties to the forest stands of the regional landscape. This stand-scale approach applied throughout the region and will be the basis for a scientific assessment of the ongoing forest conversion.

Ecological Forest Conversion

For about two decades now, forest conversion with the aim of more natural forest structures has been happening in Germany. Besides achieving higher naturalness, the economic sustainability of forestry should be secure. To achieve these goals, intensively mixed stands of broadleaved and conifer species were favored (NMLRELV 2004; Otto 1993, 1995).

Employing GIS and codifying the rules for species selection in the lower Saxony state forest conversion program "LÖWE," future forest cover and the resulting ecological and economical scenarios for the entire forest landscape of the Solling were calculated (Jansen et al. 2004).

A comparison of the actual stocking with the target state shows the extent of the initiated forest conversion. For more than 70 percent of the total forest area, a change of stand type is planned. This will increase the diversity of tree species at the stand level. However, neighborhood diversity on the landscape level will decrease (fig. 3).

Initially, very little was known about the ecological consequences of such a large-scale forest conversion; hopes, expectations and untested hypotheses dominated the scene. The recent research activities at Solling (1999-2003) focused on applying the newly acquired knowledge to actual forest management, with spatially explicit identification of ecological and economic properties at the management-unit level.

This effort used an interdisciplinary and synergistic approach comprised of more than 20 components. It was based on the different forest functions and focused on the entire forest landscape, where Solling served as a regional model. Four classes of forest functions were distinguished (Beese 1996) and quantitatively assessed: regulation, habitat, economic, and sociocultural functions.

Site Properties Model

Intensive site mapping of large forest areas is an expensive endeavor. But site property data are the most important ecological information for forest management. Classical site mapping is static; for instance, it does not consider changes in soil or climate properties over time. The landscape-oriented research approach at Solling successfully introduced GIS-based assessment of forest site properties (Schulz 2003). This laid the foundation for dynamic modeling of sites in the future. This approach also showed that spatially explicit prediction of important soil chemical indicators and humus layer properties remains difficult for now.

The newly developed site models are also the basis for spatially explicit, rule-based models of the potential natural forest cover (Jansen et al. 2002). Owing to local characteristics of species abundances, such models are only valid in a local forest landscape context. Given that restriction, our model for the lower Saxony mountain forest land proved to be valid.

Properties of Humus Layers in Pure and Mixed Stands

Depth of the humus layer is slightly less in beech stands compared to mixed and pure spruce stands. The difference is very small in young stands where humus layers are generally less developed. The depth of the humus layer in stands of intermediate age (50-80 yr) is similar to that in the old-growth stands.

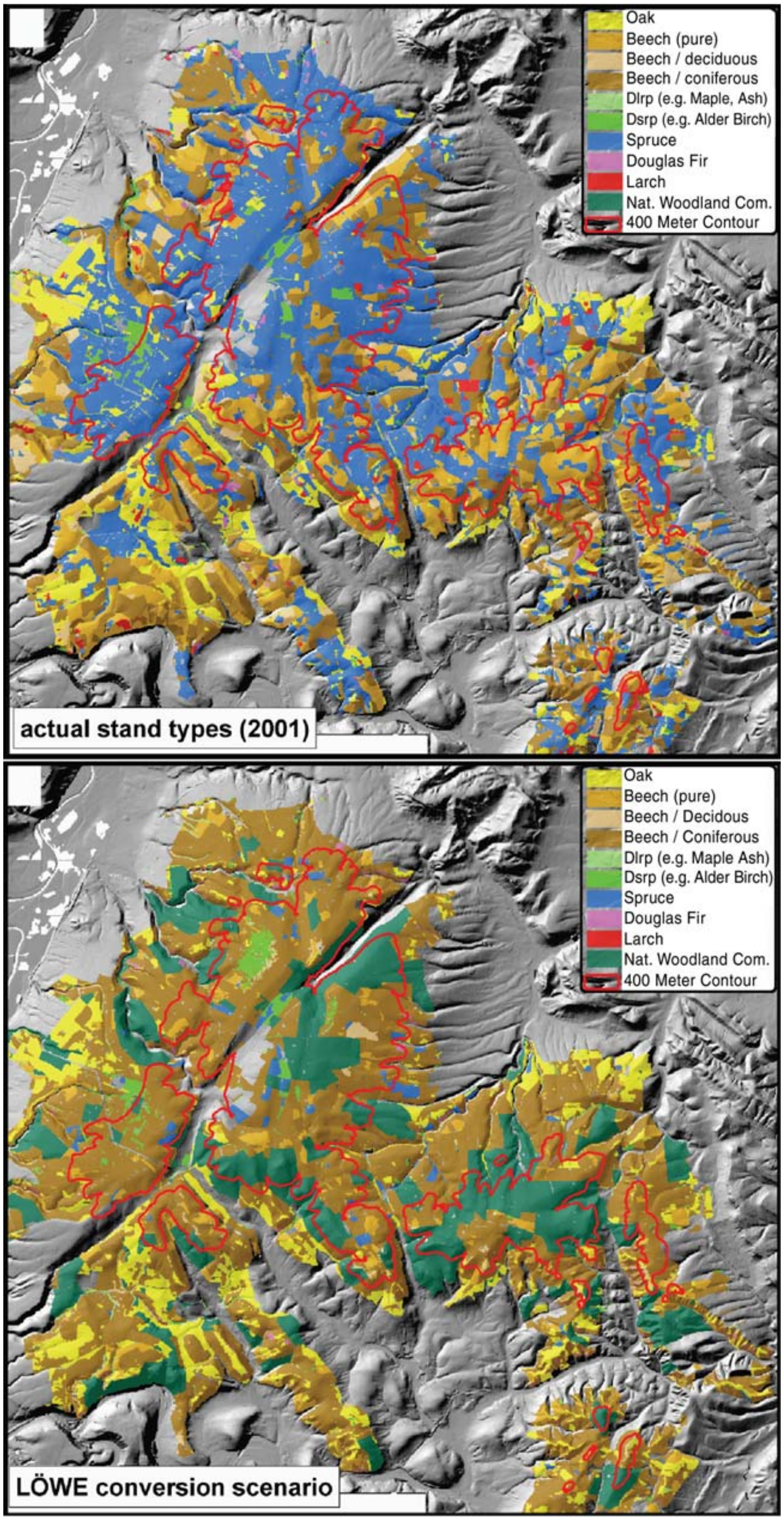

Figure 3—Current stand types (2001, left) and target stand types (right) according to "LÖWE" forest conversion program for the Solling.

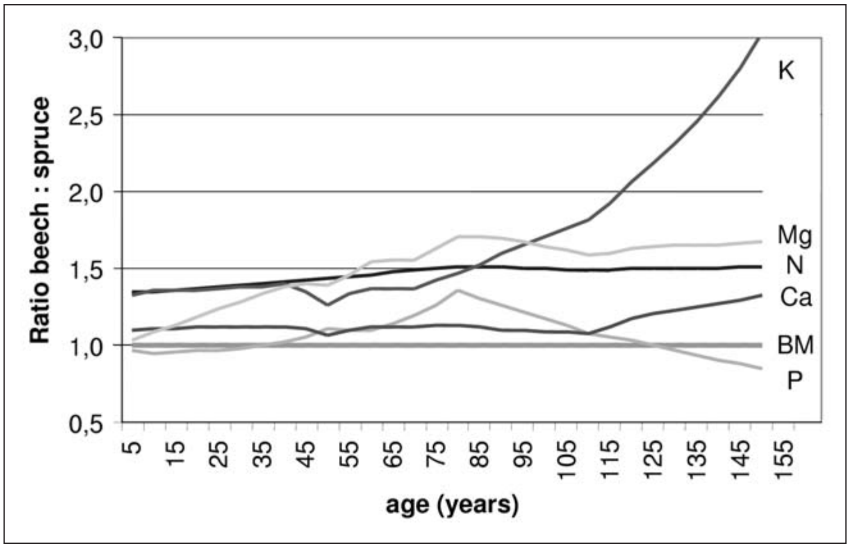

Figure 4—Temporal development of nutrient stocks bound in the biomass (BM) of beech relative to spruce in a mixed stand of both species at an assumed wood biomass ratio of 1:1 for the two species.

The investigations showed that depth of humus layer is a good indicator for carbon-, nitrogen, sulfur, and phosphorous-stores in the humus, and these elements can be predicted with high confidence. It could be further shown, that on deeply acidified soils, the admixture of beech to spruce forest did not improve humus layer quality, as was originally hypothesized (Jansen et al. 2004).

Consideration of Nutrient Exports

The study at Solling confirmed that harvest exceeding the stemwood portion of biomass strongly increased exports of nutrient elements, which are particularly critical on the poor acidic soil substrates at Solling where nutrient cations are depleted (Rademacher and Müller-Using 2004). It became evident that export of harvested beech wood meant a much larger nutrient export from the forest ecosystem than in the case of spruce wood (fig. 4). For example, potassium withdrawals resulting from harvest of beech can be two to three times more than in spruce harvests. A balanced consideration of economical and ecological aspects may lead to management decisions that counteract further nutrient losses, such as liming, fertilization, or reductions in harvest intensities.

Diversity Patterns

Contrary to initial hypotheses, the plant community in spruce-beech mixed forests is a combination of the communities found in pure stands of each species. The investigations showed that species numbers in the herb and moss layer *increase* in the sequence from quasi-natural pure beech stands to mixed stands and are largest in the artificial communities of pure Norway spruce forests (Schmidt and Weckesser 2002, Weckesser 2002). The particularly low cover and low species counts in the herb layer of the mostly natural beech stands are a consequence of the low light levels on the forest floor. The species typical of the natural beech forest community do not disappear from the spruce plantation forests, but are reduced in abundance. Structure and diversity of the herb and shrub layer seems to be more dependent on local light regimes at ground level than on tree species composition.

At Solling, where diversity was found to decrease with increasing naturalness, higher species numbers are interpreted ecologically as an indicator of anthropogenic ecosystem disturbance. The consequence of these results with respect to modern ecological forest management must be the support of *typical* species and structural assemblages in future. The catch phrase "increase of biodiversity" should be avoided as an argument for conversion toward more natural forest in situations such as Solling.

Faunistic Diversity

The patterns of faunistic diversity were more complex than the floristic patterns, owing to the higher species numbers and the mobility of species (Vollhardt et al. 2003). Nevertheless, some patterns are quite similar; in the most natural pure beech forests of Solling, fewer species were found. Stand structure, as in the case of the flora, seems to play a more important role than tree species composition.

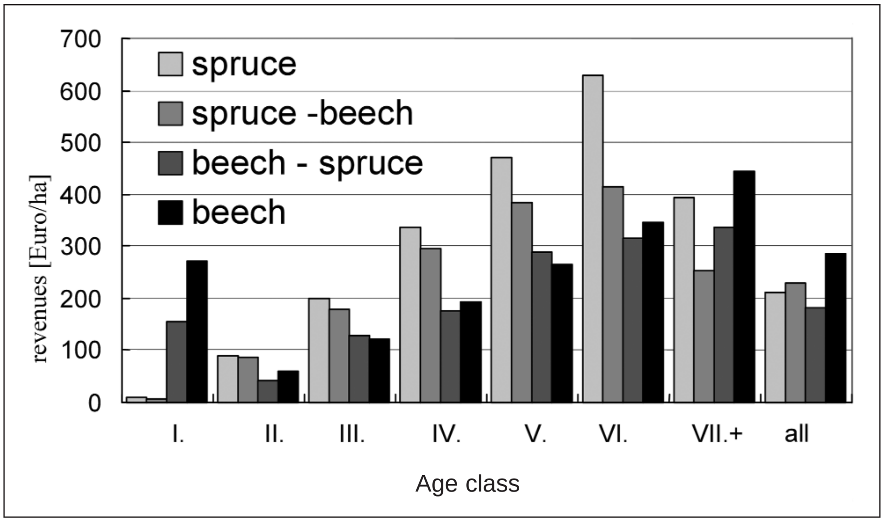

Figure 5—Revenues from forest types pure spruce, mixed with spruce dominating, mixed with beech dominating, and pure beech for different age classes in the Solling study.

Structural diversity of the forest stand obviously enhances species diversity, but "naturalness" of the tree species composition does not.

Only those insect species that damage the forest seemed less abundant in the intensively (single stemwise) mixed forests within the Solling study. However, small-scale, patchwise mixtures should also exert a controlling effect on insect pests.

Naturalness of Tree Species Composition

A central indicator for conservation is "naturalness" of the tree species composition. The latter can be calculated for each management unit on the basis of forest inventory data and maps or models of potential natural forest cover (Jansen et al. 2002). Weighting of species proportions in this exercise can either be done by area or by standing volume, leading to slightly different results.

Owing to the pronounced dominance of European beech in the potential natural forest in the Solling, the "naturalness" of stands depends on the proportion of beech in the stand. When weighting by area, the stands are 50-percent natural; when weighting by volume, the stands register as 36-percent natural. This indicates that many young beech trees are already present, but much old-growth spruce with high standing volume remains. This illustrates that naturalness can be used as a sensitive indicator of silvicultural options and strategies, which can be easily calculated for entire forest landscapes, provided that maps of the potential natural vegetation for an area are available.

Economic Aspects

Statistical analysis of revenues from 1991 to 2000 for beech and spruce in pure and mixed stands showed that revenues from beech increased with increasing proportion of beech. Similarly, revenues from spruce increased with increasing proportion of spruce. Hence both species reach maximum specific revenues in their respective pure stands (fig. 5, Möhring et al. 2004). From an economic perspective, there are no convincing reasons to favor intensively mixed forests at Solling.

Increasing the proportion of broadleaved species in forest landscapes like Solling enhances their naturalness. For the economic success of forestry, however, conifers are an important component, and will remain so in the future.

CONCLUSION

In forest management of landscapes ecologically similar to Solling, mosaic-type mixtures (small-scale mixing of pure stands) are preferable to intensive, single-stem mixtures for ecological forest conversion. Similar results are reported by Ammer and Utschik (2004). At the landscape level, various forest functions can be better fulfilled and optimized with small-scale mixing of pure stands. Intensive single-stem mixtures turned out to be disadvantageous for achieving important ecological and economic criteria.

Forest research at Solling illustrates the importance of long-term, interdisciplinary and integrated research projects.

It demonstrates the worth of such large projects. A framework of well-coordinated interdisciplinary study made these projects possible and will enable future research that addresses complex problems such as forest decline or tasks such as large-scale forest conversion.

A major challenge for future, integrated forest research will be understanding the response of forests to climatic change as the chemical environment continues to change. These issues may call for entirely new approaches to silvicultural planning.

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Silviculture Treatments for Ecosystem Management in the Sayward – The STEMS Experiment

Louise de Montigny[1]

ABSTRACT

The Sayward Forest in the Campbell River Forest District on eastern Vancouver Island, British Columbia, is a multiple-use forest of 112 000 hectares. The overall management goal is to promote timber harvesting and production in accordance with principles of integrated resource management that considers all resource values, with stewardship guided by the principles of sustainable use. The design is a replication of the Silviculture Options for Harvesting Young-Growth Production Forests project developed jointly by the Washington State Department of Natural Resources and the USDA Forest Service, Pacific Northwest Research Station. Treatments include an extended rotation (unharvested control), extended rotation with commercial thinning, clearcut with reserves, modified patch cut, group selection, uniform dispersed retention and aggregate retention. The first replication has been established in the Snowden Demonstration Forest and was harvested in 2001/2002, a second will be harvested in 2005, and a third is planned. Researchers are monitoring tree growth and stand development, coarse woody debris, windthrow, harvest cost and productivity, soil disturbance, harvesting damage to residuals, and public perception of the different treatments. An overview and status of the study and initial results from the first replication is reported.

KEYWORDS: Silviculture, silvicultural systems, Douglas-fir, western redcedar, British Columbia.

INTRODUCTION

British Columbia (BC) is a vast land encompassing an astounding diversity of ecosystems that are rich in natural resources. The province is covered by 60 million ha of forests, most (95 percent) of which is owned by the provincial government and, thus, the people of the province. Until recently, forest management meant timber harvesting and regeneration. Over the last two decades, however, there has been a fundamental shift in the way people value the forests of BC. Nontimber resources, recreation, tourism, water quality, and wildlife habitat, have been increasingly important and First Nations land claims over much of the province have yet to be resolved. Throughout the last decade, there has been an increased use of a diversity of silvicultural systems to meet multiple resource objectives. How these silvicultural systems achieve multiple resource objectives and their sustainability is still in question. The provincial government has invested in several excellent silvicultural systems to examine the long-term effects of these systems. This paper describes one or these experiments, Silviculture Treatments for Ecosystem Management in the Sayward, or STEMS.

The Sayward Forest

The Sayward Forest, also known as the Sayward Landscape Unit or "the Sayward," exemplifies the increasing multiple-use demands on forest resources. The Sayward covers 112 000 ha in the Campbell River Forest District on central Vancouver Island. Over the past century, logging or fire has disturbed most forests in the Sayward. As a result, 63 percent of the area consists primarily of second-growth Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) forests between 40 and 80 years old. The few old-growth stands remaining are fragmented and primarily at higher elevations. The Sayward is an extremely valuable recreation resource,

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with three provincial parks, 67 Forest Service recreation sites, and numerous hiking and mountain biking trails. The Sayward also features important wildlife habitats, cultural and heritage resources, mineral values, a source of domestic water, and is a source of nontimber forest products such as salal (*Gaultheria shallon*), mushrooms, and berries. With a 20- to 50-percent predicted rise in population on eastern Vancouver Island (Rose 2002), the demand for resources in the Sayward is expected to increase dramatically in the next decade.

The Sayward Landscape Unit Plan (Anon. 2003) has identified the importance of the multiple resource use in the Sayward. The overall goal is to promote timber harvesting and production in accordance with principles of integrated resource management that considers all resource values, with stewardship guided by the principle of sustainable use. The Silviculture Treatments for Ecosystem Management in the Sayward (STEMS) experiment will help determine how best to meet the goals and targets set out in the Sayward Landscape Unit Plan for multiple-use objectives.

METHODS

Experimental Design and Objectives

The STEMS experiment is a rigorously designed, replicated, long-term silvicultural systems experiment that tests seven treatments: extended rotation (nontreatment control), extended rotation with commercial thinning, aggregate and uniform dispersed retention systems, group selection and modified patch cut systems, and a 10-ha clearcut with reserves. The first replication (STEMS 1) was established in the Snowden Demonstration Forest and harvested through the Small Business Forest Enterprise Program. The second has been established at Elk Bay and will be harvested by International Forest Products Ltd. in January 2005. A third replication is planned for harvesting in 2007 by B.C. Timber Sales.

The STEMS experiment is part of a larger study that includes three replications of six treatments in the Capitol Forest near Olympia, Washington. This study, titled "Silviculture Options for Harvesting Young-Growth Production Forests," for simplicity, will be referred to here as the Capitol Forest Project. The treatment targets used in the STEMS project are similar to that of the Capitol Forest Project (Curtis et al. 2004, Marshall and Curtis 2005), with two exceptions: the two-aged treatment at the Capitol Forest is called the uniform dispersed retention treatment at STEMS, and the STEMS study added a seventh treatment, aggregated retention, because of its increased use in coastal BC.

The overall goals of the STEMS and Capitol Forest projects are, within mature second-growth Douglas-fir stands, to

- Create replicated examples of alternative harvest practices and silvicultural regimes that can be used as a demonstration area by foresters and planners in ecosystem management,
- Provide quantitative information for evaluation of feasibility and costs of alternative regimes and their long-term effects on production of timber volumes and values and other nontimber values, and
- Evaluate the effectiveness of contrasting silvicultural systems in reducing environmental and visual impacts of forestry operations while supplying high timber outputs over time.

The STEMS experiment consists of three studies with specific objectives:

- Forest Productivity Study—to quantitatively compare forest productivity, including residual trees, regenerating trees, understory vegetation, light environments, mortality and windthrow, and coarse woody debris, under contrasting silvicultural systems over an extended period.
- Economics Study—to quantitatively compare timber outputs, production costs, and operational factors associated with harvesting, including post-harvest residual tree damage, soil disturbance and compaction, and slash loading.
- Public Perception Study—to compare public response to the various silvicultural treatments at site and landscape levels.

Site Description

The first replication of the STEMS experiment has been established at the eastern end of the Snowden Demonstration Forest which is located in the southern portion of the Sayward Landscape Unit within the Very Dry Maritime Coastal Western Hemlock (CWHxm) biogeoclimatic subzone (Green and Klinka 1994). The area was established as a demonstration forest in 1987 to raise public awareness about integrated resource management. The forest in this area is predominantly Douglas-fir, with a minor component of western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and western redcedar (*Thuja plicata* Donn). According to plantation maps, the area was planted in 1946 following clearcut logging and burning, so average stand age was 55 years in 2001 at the time of harvest.

Table 1—Summary description of key features for each treatment

Treatment	Harvest and residual objectives	Stand structure objectives	Treatment unit size (ha)	Harvested opening size (ha)	Return interval (years)
Extended rotation	Deferred harvest	Even-age	12	0	80
Extended rotation with commercial thinning	350 stems per ha	Even-age	19	0	20
Group selection	13 percent area cut every 10 years	Multi-age	22	0.06 to 0.50	10
Patch cut	13 percent area cut every 10 years	Multi-age	36	0.55 to 2.0	10
Uniform dispersed retention	40 stems per ha	Two-age	18	18	80
Aggregate retention	2.6 ha internal, 5.5 ha riparian reserves	Two-age	26	4.4, 6.4, 11.5	80
Clearcut with reserves	All stems removed with 0.3 ha reserve	Even-age	11	11	80

Ecosystem mapping of area identified six site series, the most common being zonal 01 Douglas-fir–salal (slightly dry to fresh soil moisture regime (SMR) and very poor to medium soil nutrient regime (SNR)) and 05 western redcedar–swordfern (slightly dry to fresh SMR and rich to very rich SNR). Soils were predominantly Ferro-Humic Podzols with moder humus form, sandy-loam structure, coarse fragment content averaging about 40 percent, and depth averaging 50 to 80 cm. The topography of the area is gently rolling. Large rocky knolls, classified as site series 03 Douglas-fir/shore pine–Cladina (very dry SMR and very poor to medium SNR) were avoided as much as possible, but a number of smaller knolls are scattered throughout treatment unit 5 (patch cut). A root disease survey found *Phellinus weirrii* ((Murr.) Gilb.) infections at an overall infection level of 6.1 percent. An objective of the treatment unit designation was to include a more or less equal proportion of 01 and 05 sites series and root disease within each treatment, although this was not always possible. The patch cut, group selection, and extended rotation treatment units had a smaller component of 05 site series, and the patch cut had a higher component of 03 site series.

The total area under prescription is 186.4 ha; the area within treatment unit boundaries is 139.3 ha (75 percent of the gross area), and the areas of retention (including internal and external reserves, not including individual tree reserves) is 52 ha (27 percent of the gross area).

Treatment Description

A summary of the key features of each treatment is shown in table 1. The treatment unit size varies depending on the expected variation in stand structure after treatment, from 11 ha for the clearcut to 36 ha for the patch cut. Stand structure objectives range from even-aged to two-aged to multi-aged. Return intervals range from every 10 years for the multi-aged treatments to 80 years for the even- and two-aged treatments. The relatively frequent return interval of 10 years was chosen for the STEMS 1 site because of its easy access and location within a designated demonstration forest. The 80-year return interval is based on a biological rotation age for Douglas-fir on this site. The number of residual trees targeted in each treatment unit differed: for the extended rotation, 100 percent of the trees were to be retained; for the extended rotation with commercial thinning treatment 350 stems per ha of evenly dispersed overstory trees and 150 understory western redcedar were retained; for the dispersed retention 40 evenly dispersed stems were retained per ha; in the aggregate retention residual trees were to be left in groups ranging from 0.02

ha to 1.2 ha and in riparian reserves, up to 5.5 ha. Immature western redcedar were retained as individuals wherever possible.

As this was an operational experiment, harvesting was coordinated by the BC Ministry of Forests, Small Business Program and was contracted through a public bid process with different blocks being awarded to different licensees. Some blocks were further sub-contracted, and all harvesting was completed through summer/fall/winter of 2001 and early 2002. Trees in all treatments were hand-felled. Loader forwarding was used as the primary method of extraction in the dispersed retention, aggregate retention and clearcut treatments. Cable yarding was used in the extended rotation with commercial thinning treatment. A combination of loader forwarding and cable yarding was applied in the patch cut treatments. Within root rot pockets, the stumps were to be pulled and inverted by the harvesting contractor to prevent the subsequent spread of disease. Areas to be stumped ranged from 1 ha to 7.8 ha (table 2). All treatment units with a regeneration cut were to be replanted with 1200 stems per ha of PSB 415D 1+0 Douglas-fir in March/April 2002.

The Forest Productivity study is based on repeated measurements on a grid of 15 to 25 permanent plots per treatment, maintained for the life of the experiment. Supplementary short-term studies of harvesting costs and visual impacts are being done in cooperation with other organizations. Details of the methodology and preliminary results of the forest productivity study are described in de Montigny (2004). The description of each treatment is summarized in table 1. The economics study was done by the Forest and Engineering Research Institute of Canada (FERIC, and details of the methodology and results are described in Evans et al. (2003). The public perception study is underway; the surveys have been completed and the analysis and reporting are in progress by the Forest Practices Branch, BC Ministry of Forests.

RESULTS

Pre- and post-treatment statistics are found in table 2. The treatment units in the southern portion of the experimental area, including the aggregate retention, dispersed retention, clearcut with reserves, and the extended rotation with commercial thinning, had significantly higher initial densities, higher relative density and lower quadratic mean diameter than other treatment units. This is explained by a much larger component of western redcedar in the understory, and the average stand ages appear to be different for the two areas: 60 years in the northern portion and 55 years in the southern portion. In contrast, the group selection and patch cut treatments had lowest relative density, and this is probably a reflection of the slightly higher age and a higher proportion of 01 and 03 site series with their corresponding lower site index.

Actual volume removed from each of the treatments ranged, from 0 percent for the extended rotation, to 53 percent for the extended rotation with commercial thinning, to 100 percent for the clearcut (not including the small reserve). In the group selection and patch cut treatments, volume removed ranged from 15 to 19 percent; for the aggregate and dispersed retention treatments, volume removed ranged from 83 to 89 percent.

Extraction costs were highest for the extended rotation and commercial thinning treatment at \$187.52/m^3, and lowest for the clearcut, aggregate retention and dispersed retention treatments at \$3.83./m^3, \$4.71/m^3, and \$5.86/m^3, respectively (Evans et al. 2003). The shift-level study showed that for loader forwarding, the costs did not change considerably with the level of retention. Unfavorable ground conditions in the patch cut treatment required the use of cable yarding, and thus increased costs.

Tree damage (table 3) was highest in the dispersed retention block, with 17 percent of all trees showing some form of damage, primarily caused by forwarding activities. In the extended rotation with commercial thinning treatment, 15 percent of trees were damaged mostly near the base of standing trees. This occurred when yarded stems rubbed against the residual trees. In both treatments the damage is most likely attributed to inadequate care by the contractors. The aggregate retention, group selection and patch cut treatments had the lowest damage at 3, 1, and 0 percent respectively.

The levels of soil disturbance (table 3) for each treatment were well below the allowable maximum set in the prescriptions for stratums that were not stumped. The lowest levels of soil disturbance occurred in areas that were not stumped within the patch cut, group selection and extended rotation with commercial thinning treatments (table 3). Slightly higher levels were found in the treatments that had loader forwarding activity, including the clearcut, aggregate retention and dispersed retention blocks. For areas that were stumped, the level of disturbance ranged from 5.8 to 13.1 percent, which was still very low considering this type of treatment.

Rates of windthrow (table 3) were highest in the dispersed retention treatment where 46 percent of the residual

Table 2—Pre- and post-harvest stand statistics by treatment unit

Treatment		Density (stems/ha)		Basal area (m^2/ha)		Total volume (m^3/ha)		Merch volume (m^3/ha)		Quadratic mean diameter (cm)		Relative density	
Extended rotation	Preharvest	607	a	53	ab	610	ab	580	ab	33.1	c	9	ab
	Post-harvest	607		53		610		580		33.1		9	
	Percent change	0		0		0		0					
Extended rotation with commercial thinning	Preharvest	1325	b	69	c	712	b	651	c	26.3	ab	14	c
	Post-harvest	636		37		388		359		27.3		7	
	Percent change	52		46		46		45					
Group selection	Preharvest	725	a	48	ab	499	a	465	ab	28.5	bc	9	a
	Post-harvest	578		41		405		381		28.5		8	
	Percent change	20		15		19		18					
Patch cut	Preharvest	763	a	44	a	452	a	418	a	28.0	ab	8	a
	Post-harvest	575		36		372		345		27.3		7	
	Percent change	25		18		18		17					
Uniform dispersed retention	Preharvest	1210	b	55	b	581	ab	530	b	24.6	a	11	b
	Post-harvest	51		6		57		54		38.2		1	
	Percent change	96		89		90		90					
Aggregate retention	Preharvest	1208	b	55	b	571	a	521	b	25.0	a	11	b
	Post-harvest	247		10		96		86		26.5		4	
	Percent change	80		82		83		83					
Clearcut with reserves	Preharvest	747	a	53	ab	587	ab	551	ab	30.1	bc	9	ab
	Post-harvest	0		0		0		0		0		0	
	Percent change	100		100		100		100					

Note: Similar lowercase letters indicate no significant difference between treatments.

trees were uprooted and a further 15 percent were left leaning. This excessive loss resulted from two major wind events in November and December 2001 and again in December 2002. Trees that had been treated with a spiral crown pruning (seven trees/ha in which 30 to 50 percent of the live crown was removed in a spiral fashion over the entire live crown) were still standing straight. By comparison, 18 percent of trees in the aggregate retention were either uprooted or leaning. In the other treatments, the percentage of trees either uprooted or leaning was as follows: 8 percent in the extended rotation with commercial thinning, 4 percent in patch cut, 2 percent in the group selection, and 0.5 percent in the extended rotation. Windthrow around block boundaries were surveyed and the clearcut with reserves and the dispersed retention treatment units were the hardest hit, although all cutblock edges experienced some windthrow.

Planted seedlings have been very susceptible to elk browsing. A resident herd of elk is often seen browsing on seedlings over the winter and early spring. The most heavily browsed areas occurred in the group selection (40 percent)

Table 3—Forest health results

		Soil compaction		Residual tree damage					
	Root rot treatment	In areas not stumped	In stumped areas	Total trees damaged	Damage from falling	Damage from yarding	Damage from windfall	Windthrow of residual trees	Seedlings browsed
	ha	Percent							
ER[a]	_	_	_	_	_	_	_	0.1	_
ER with commercial thinning	_	0.5	_	15	12	88	0	4	_
Group selection	1.1	0.4	6.6	1	57	14	14	1	40
Patch cut	1	0	5.8	0	100	0	0	1	14
Uniform dispersed retention	1.3	2.7	12.7	17	0	81	19	46	17
Aggregate retention	7.8	2	7.3	3	60	30	10	8	20
Clearcut with reserves	4.4	0.8	6.6	_	_	_	_	_	31

[a] ER = extended rotation

and clearcut with reserves (31 percent) treatment units (table 3). In other treatment units, 14 to 20 percent of planted seedlings were browsed.

Initial results of the public perception survey indicate the public acceptance trends are similar at the landscape level and the site level—the more a stand has been modified, the lower the public acceptance rating. The one exception to the trend was the patch cut, which at the landscape level appears small, but at the site level appears large and therefore, is viewed more critically.

CONCLUSION

The first of three replications of the Silviculture Treatments for Ecosystem Management in the Sayward (STEMS) project has been established in the Snowden Demonstration Forest, located in the southern portion of the Sayward Landscape Unit on eastern Vancouver Island. The treatments include extended rotation, extended rotation with commercial thinning, uniform dispersed retention, aggregate retention, group selection, patch cut (0.5–3 ha) and clearcut with reserves. These different silvicultural systems and treatments have created some initial diversity in forest structure including at least two canopy layers (vertical structure) and spatial patchiness (horizontal structure). The stands are dominated by Douglas-fir with a minor component of western hemlock, and many of the treatment units have a substantial proportion of western redcedar understory.

Ongoing studies with STEMS 1 include studies of forest productivity, including stand development, regeneration, windthrow and coarse woody debris recruitment; an economic study on harvesting production and impacts of residual tree damage and soil disturbance; and a public perception study on visual quality and public response. Initial results are listed below:

- Levels of soil disturbance for stumped and not stumped areas were within acceptable limits.
- Damage to residual trees appeared highest in commercial thinning (15 percent) and dispersed retention (17 percent) treatment units.
- Planted seedlings have been heavily browsed by elk in the group selection (40 percent) and clearcut (31 percent) treatments. In other treatment units, 14 to 20 percent of seedlings were browsed.
- Windthrow losses of 46 percent in the dispersed retention block was the result of major wind events in the first two years after harvesting.

Continued monitoring of the STEMS experiment will help determine how best to meet the operational goals and targets set out in the Vancouver Island and Sayward Land Use Plans for multiple-use objectives. The results of this experiment will be used to improve forest management decisionmaking and policies regarding alternatives to clearcutting.

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Tree and Understory Responses to Variable-Density Thinning in Western Washington

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ABSTRACT

The Olympic Habitat Development Study was initiated in 1994 to evaluate whether active management in 35- to 70-year-old stands could accelerate development of stand structures and plant and animal communities associated with late-successional forests. The study used a variable-density thinning prescription as the main tool to alter stand structure; the prescription entailed creating gaps and retaining uncut areas, and thinning the remaining forest matrix. We assessed tree damage (primarily windthrow) following thinning, 5-year tree growth, and 3-year vegetation development in control and thinned plots. Windthrow damage was minor in most plots, occurring primarily in stands with high height-to-diameter ratios and located in vulnerable topographic positions. Tree growth responded positively to thinning. In addition, tree growth differed spatially—trees near gaps or along skid trails had better-than-average growth whereas trees near uncut patches had poorer-than-average growth. Understory vegetation responded to thinning with increased percentage of cover and number of herbaceous species in thinned areas and in created gaps. Percentage of cover of mosses and liverworts was greatest in undisturbed areas. Early results indicate that the thinning is operationally feasible and demonstrate that the variable-density thinning increases spatial heterogeneity within the stands.

KEYWORDS: Tree growth, windthrow, implementation, new techniques.

BACKGROUND

The Olympic Habitat Development Study was initiated in 1994 to evaluate whether variable-density thinning and management of coarse woody debris could accelerate development of stand structures and plant and animal communities commonly associated with late-successional (or old-growth) forests. The study is a joint venture of the Olympic National Forest and the Pacific Northwest Research Station (Silviculture and Forest Models team, Resource Management and Productivity Program). Planning for the study also involved participants from the University of Washington, the Washington Department of Natural Resources, the U.S. Fish and Wildlife Service, and the Washington Department of Fish and Wildlife. Plot sizes were selected to be large enough to assess population responses of small mammals. In addition, the treatments manipulating coarse woody debris were designed specifically to enhance wildlife habitat. Pretreatment surveys of forest-floor small mammals and arboreal rodents were conducted on all plots (Carey and Harrington 2001). Post-treatment surveys of small mammals and arboreal rodents were collected in 2004 in a subset of the plots but that data, and aspects of the study related to course woody debris, are not included in this report.

Variable-density thinning is a relatively recent term for thinning in a nonuniform manner, typically with wildlife or biodiversity along with traditional economic objectives. Despite much discussion about the potential of this approach, as well as the implementation of many projects involving variable-density thinning in the western United States and Canada in the last 10 years, little information is available to managers on stand responses. This report provides early findings on treatment implementation, logging damage and

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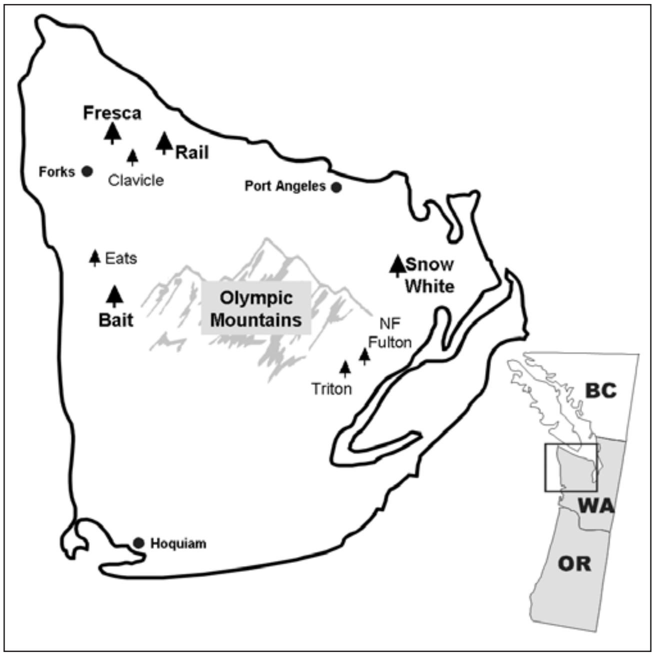

Figure 1—The eight blocks of the Olympic Habitat Development Study (tree symbols) and towns (filled circles) in western Washington. The four locations for which information is presented in this report are represented by the larger symbols.

windthrow following variable-density thinning, tree growth in relation to different components of the thinning, and understory responses.

METHODS

Study Areas

Eight blocks, 50 to 70 ha in size, were selected in 35- to 70-year-old conifer stands on the Olympic National Forest in western Washington (fig. 1). Four or five, 6.5- to 9-ha plots were located in each block such that the plots were similar in forest condition and were buffered to avoid major changes in forest cover adjacent to their boundaries. This report covers responses for four blocks that were treated between 1997 and 2000.

The four blocks differed physiographically from broad flat river valleys at low elevations (150 to 300 m) to steep (>50 percent slope) side hills at higher elevations (580 m) (table 1). Soils were generally silty or sandy loams. Mean annual precipitation ranges from 145 to about 320 cm, with wet winters and dry summers.

Table 1—Site and stand characteristics for the first four blocks thinned in the Olympic Habitat Development Study[a]

Block	Elevation	Annual precipitation[b]	Primary tree species	Stocking	Basal area
	m	*cm*		*Trees per ha*	$m^2.ha^{-1}$
Bait	190-335	317.5	Western hemlock, Douglas-fir	1095	63
Fresca	150	265	Western hemlock, Sitka spruce	585	63
Rail	275	239	Douglas-fir, Western hemlock	360	46
Snow White	430-580	145-195	Douglas-fir	709	45

[a] Stand characteristics based on pretreatment surveys.

[b] Annual precipitation estimates based on the parameter-elevation regressions on independent slopes model (PRISM) (U.S. Department of Agriculture Natural Resources Conservation Service et al. 1999).

The blocks differed in initial stand density and basal area (table 1). Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) were present on all plot although they were not necessarily the major species; Sitka spruce (*Picea sitchensis* (Bong.) Carr.), western redcedar (*Thuja plicata* Donn ex D. Don), Pacific silver fir (Abies amabilis Dougl. ex Forbes), red alder (*Alnus rubra* Bong.), and big-leaf maple (*Acer macrophyllum* Pursh) were locally common but generally present as minor species or only present at a few plots. Two blocks (Snow White and Bait) had been planted with Douglas- fir, but both also had substantial amounts of naturally regenerated western hemlock. One of the blocks (Bait) had been precommercially thinned, which reduced species diversity and stocking, but the stands still had fairly high stocking levels when the study began. Two other blocks (Snow White and Rail) had been commercially thinned prior to the implementation of the study, but because the thinning at Snow White occurred a fairly long time ago (in the early 1970s), and the sanitation thinning at Rail (in 1986) removed relatively little basal area, these past activities were mostly evident only by the presence of old skid trails.

Treatments

The variable-density thinning prescription designed for this study called for a series of skips (untreated patches that were "skipped over" during the thinning operation) and gaps (stand openings) to be embedded within a thinned matrix (fig. 2). We call this prescription "thinning with skips and gaps." The skips were about 0.1 to 0.3 ha and covered 10 percent of the plot area. Skips were located to preserve as many large-diameter snags as possible with the proviso that a maximum of one skip was retained in each quarter of the plot (about one per 2.0 ha). Equipment entry was not allowed in the skips, and gaps were placed at least 20 m from the skips, thus maintaining the skips as areas within the stand with minimal disturbance. Gaps were openings 0.04 to 0.05 ha and covered 15 percent of the plot area; existing gaps associated with pockets of root rot or with past thinning operations were included in the 15 percent. All merchantable stems (> 20 cm diameter at breast height (d.b.h.)) were removed from gaps with the exception of species of low local abundance (e.g., hardwoods, western redcedar, and Pacific silver fir). The matrix, covering the remaining 75 percent of the treatment area, was thinned by removing 25 percent of the stand basal area, primarily from the lower crown classes.

Each block consisted of one uncut control plot and three or four plots that received the same variable-density thinning prescription but differed in the degree of clumping of

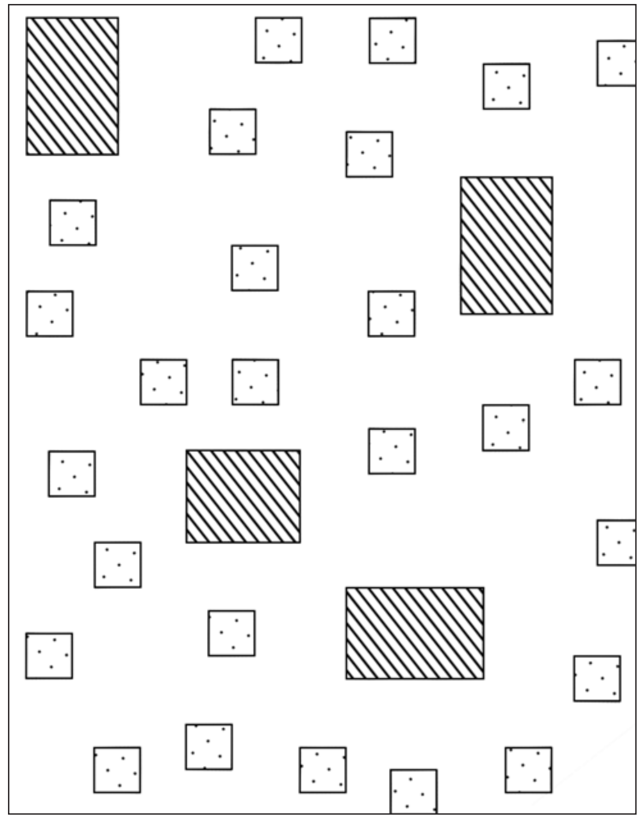

Figure 2—Example of distribution of unthinned skips (dotted areas) and gaps (diagonal lines) at one of the variably thinned plots in the Olympic Habitat Development Study.

residual logs and slash (see Reutebuch et al. 2002 for details). Skips, gaps, and trees to be cut were predesignated, subsequently evaluated, and, if necessary, corrected for adherence to the research prescription. Each block was part of a separate timber sale with additional volume from other stands outside the study plots included in most of the sales. No special restrictions (other than no-equipment entry within skips) were added to the contracts. To facilitate timely implementation of the study, the contracts generally had a 2-year life; however, depressed timber markets and changes in environmental regulations, caused thinning to be considerably delayed. The first two blocks (Fresca and Rail) were thinned in 1997, and the second two blocks (Bait and Snow White) were thinned in 1999 and 2000. By 2004, six of the eight study blocks had been thinned.

Tree and Other Plant Measurements

Eighteen plots were surveyed for logging and wind damage three winters after thinning was completed (most windthrow in this area occurs during winter when soils are saturated and windspeeds are high). Damaged trees were coded as to type of damage and measured for diameter; these data along with tree position were then entered into a geographic information system. Damage levels were assessed in relation to species, topographic position, and location in relation to components of the thinning treatments. Damage was also related to pretreatment stand information including basal area and heights of dominant trees. Five-year tree growth was assessed on 1.44-ha stem-mapped plots. Growth plots were positioned to include two gaps and all, or portions of, two skips. Plots were measured during the dormant season immediately after completion of the thinning, and at Fresca and Rail, were measured again 5 years later. All trees taller than 1.3 m were initially measured and their location mapped. Due to large numbers of ingrowth trees in some areas, a separate subsample of regeneration and ingrowth was initiated at the 5-year remeasurement. The 5-year remeasurement data for the two stem-mapped plots were used to summarize tree growth for the entire stem-mapped plot, by species, by treatment components within the stem-mapped plot (i.e., skips versus thinned areas), and in relation to distance from skid trails and internal edges created by the treatments. The 5-year remeasurement of the stem-mapped plots at Bait and Snow White is scheduled for winter 2004/2005. Data from the 5-year regeneration and ingrowth subsampling are available from all four areas.

Pretreatment vegetation surveys included four types of subplots to accommodate different size categories of vegetation including herbaceous plants, shrubs, seedlings, saplings, overstory trees, mosses, and lichens. Transects 10 m long were used to record larger understory vegetation including ferns and nontrailing woody shrubs. Three 0.1-m^2 plots were placed along each transect to assess percentage of cover of smaller plants, mosses, and other features. Circular plots (5.64- and 2.0-m radius) were used to sample overstory and understory trees as well as lichens. In total, 39 transects and 78, 0.1-m^2 plots were sampled within each plot. Additional vegetation sampling was conducted within the stem-mapped plot at each site and purposefully placed in areas that would be exposed to different treatments.

Post-treatment assessments concentrated on control plots and the thinned plots containing the stem-mapped areas. Although fewer total plots were sampled post-treatment, sampling intensity was increased to capture the anticipated differentiation of the understory. In addition, sampling methods were simplified by eliminating measurements along transects and including all understory components within the 5.64-m fixed-radius plot. The plot size for cover assessments for the smaller plants, mosses, and ground features was increased to 0.4 m^2. Vegetation data were summarized for the control plot and separately for the three subtreatment components of the thinned plots (skips, thinned matrix, and gaps).

RESULTS AND DISCUSSION

Implementation of Variable-Density Thinning

The experimental prescription was implemented with only minor problems. Variable-density thinning increased the variability in volume removed per cruise plot and thus necessitated an increase in the number of cruise plots per unit area. Stratified sampling partially compensated for this, but more resources for timber cruising were still needed to meet the accuracy standard for lump-sum sales.

Some loggers were initially ill-informed of contract requirements and expressed concern about restrictions associated with the research function or the different type of prescription. They quickly realized, however, that the prescription was not difficult to implement. In some areas, more trees adjacent to the skid trails were removed than anticipated (as approved by the timber sale administrator to facilitate operations). In other areas, some marked trees were left uncut owing to poor markets, but overall, the prescription was implemented as designed.

In a uniform thinning operation, it can be difficult to fell trees in dense stands; however, the presence of gaps in the variable-density thinning facilitated the felling of trees in the gaps and in the thinned matrix. Because the thinning in the matrix area was a light, low thinning, most of the larger trees felled were in gaps or removed as part of skid trail installation. On blocks where ground-based equipment was used, gaps did receive more equipment traffic than the thinned matrix because of greater volume removal. In addition, owing to the relative contribution of gaps to the overall volume removed, skid trails were generally routed through or along the edges of the gaps. Gaps were also frequently used as temporary log decking areas.

No equipment was allowed in the skips which in some cases forced operators to make sharp turns or reverse logging equipment when reaching the skip boundary. Rutting caused by the turning of equipment was generally shallow, becoming inconspicuous within a few years following thinning.

Damage Associated With Thinning

Logging damage was generally low (table 2). Activities were halted when soils became too wet to continue without risking major rutting and compaction, or where specific equipment or practices were resulting in damage to residual trees or soil. The usual branch breakage and occasional stem

Table 2—Logging damage in stem-mapped plots at four blocks of the Olympic Habitat Development Study

Block	Any Damage	Severely damaged[a]
	Percentage of trees	
Bait	0.3	0.0
Fresca	4.2	.2
Rail	4.3	.1
Snow White	4.5	1.6

[a] Severely damaged trees were those with very poor growth potential or substantially reduced economic value.

scarring associated with timber falling and extraction were observed, but few trees were affected overall. Removal of bark on the lower bole and exposure or damage to shallow roots were the most common forms of damage observed. Small trees and shrubs were often pushed over by equipment; a timber sale administrator referred to trees less than 15 cm as "like air" to the loggers, implying that they did not see them or were not concerned about running over them. Thus, in some areas with substantial advanced regeneration, many small stems were destroyed in the harvest operation. This was expected and may have been desirable in areas that had prolific advanced regeneration of western hemlock prior to thinning (see below for information on tree regeneration). Falling branches from overstory trees also damaged some residual understory and midstory trees, resulting in top or branch breakage or stem scarring. Large shrubs were also commonly knocked over; some were killed, whereas others resprouted.

Overall, logging damage to the residual timber and soils was low. Some additional restrictions are advisable, however, if understory and midstory trees or large shrubs are desired to meet specific objectives. For example, Wender et al. (2004) suggested that some large shrubs be protected if fruit production is critical.

Wind Damage

Wind-related damage differed substantially from plot to plot across blocks (fig. 3). In terms of total number of wind-damaged stems per hectare, only 1 of the 14 thinned plots had moderate to heavy damage (>50 trees damaged per hectare), 2 of the thinned plots had minor to moderate damage (20 to 25 trees per hectare), and damage at the other 11 thinned plots and the 4 control plots was very minor (fewer than 5 trees per hectare). Only two plots (one at Bait and one at Fresca) had more than 10 trees per hectare greater than 20 cm in diameter damaged by wind following thinning. Damage was observed to individual trees as well as groups of trees. Damage was occasionally clumped as one tree would fall into a second or third tree and a whole group would come down. Some smaller trees were bowed over and some trees snapped off; however, the majority of wind-related damage was windthrow where all or a portion of the root system was pulled out of the ground.

Stand height-to-diameter ratio (H:D) (as estimated from trees measured to calculate site index prior to thinning) appeared to play a role in predisposing stands to wind damage (table 3). Stands with higher H:D values experienced the most damage. The timing of the thinning in relation to major windstorms also appeared to affect severity of damage. One plot at Bait had very little wind damage even though it had the same H:D ratio (80) and was in a very similar topographic position as the two plots in the block that had the most damage. The plot with little damage was thinned several months after the other plots in the block, thereby avoiding a major windstorm that occurred while the other plots were being thinned. The greatest wind damage generally occurred along skid trails and adjacent to gaps located on ridgetops (Bait) or on a small hill where wind funneled down a river corridor (Fresca). Most wind-damaged trees were western hemlock, but because we did not

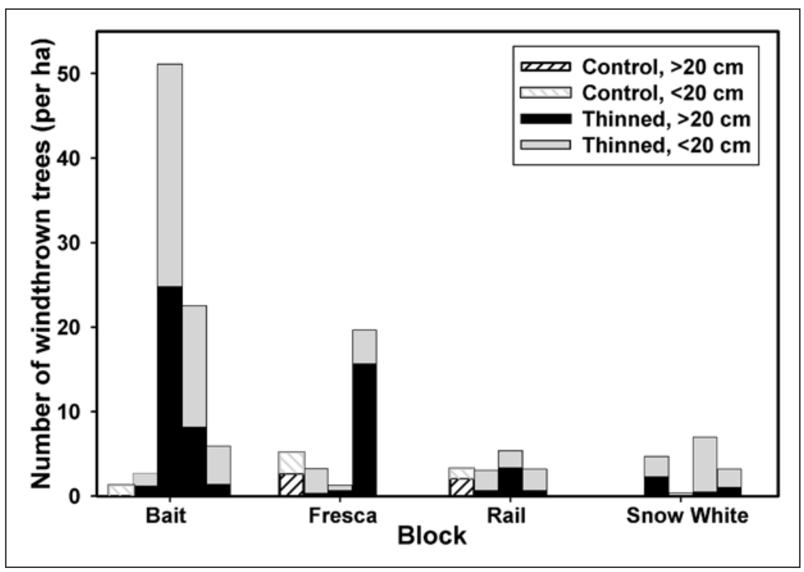

Figure 3—Number of windthrown stems per hectare less than or greater than 20 cm for 4 control plots and 14 variably thinned plots in the Olympic Habitat Development Study. There was 1 control plot and 3 or 4 thinned plots at each block. At Snow White, no windthrow occurred in the control plot.

Table 3—Percentage of thinned plots by level of wind damage and height-to-diameter ratio[a]

Height-to-diameter-ratio	Level of wind damage[b]	
	>5 trees per ha	>20 trees per ha
	Percentage of plots with damage	
<65	0	0
65-75	17	0
>75	100	67

[a] Based on trees used to calculate site index prior to thinning.

[b] Based on 14 thinned plots assessed 3 years after variable-density thinning.

have detailed information on species occurrence by diameter class on each plot, it was not possible to say whether hemlock was more susceptible or simply more prevalent.

Windthrow can be an undesirable side effect of thinning, especially during the first 3 to 5 years following treatment (Cremer et al. 1982). This study did not include uniformly thinned stands so we cannot test differences in windthrow between uniform and nonuniform thinning treatments—but it does not appear that the variable-density thinning prescription, by itself, resulted in greater risk of wind damage. Rather, the factors that commonly predispose thinned stands to windthrow, such as high H:D ratio and topographic position, were involved. Results suggest that if variable-density thinning is to be imposed on high-risk stands in the future, windthrow could be minimized by locating gaps, skid trails, and landings on ridgetop positions where feasible. If that is not possible, gaps could be eliminated or made smaller during the first entry. Earlier thinning entries would also reduce risk by lowering H:D ratios; thus, managers may wish to prioritize stands for earlier thinning if they are in high-risk topographic positions or have high stem densities likely to result in high H:D ratios. Although we were somewhat disappointed at the level of windthrow in the 3 stands that lost more than 10 trees per hectare, even these stands at present retain adequate stocking to meet the original management objectives. In addition, the greater loading of coarse woody debris and increased spatial variability of tree distribution resulting from windthrow are both characteristics consistent with the overall management objectives for this prescription.

Tree Growth

Tree growth in the two stem-mapped plots with 5-year post-treatment data responded positively to the variable-density thinning with increased diameter growth. Although this may seem like an obvious conclusion, we were not sure if these older stands (60+ years old) would respond to a light thinning in such a short period. In the Fresca block, tree growth also differed by spatial position–trees near gaps or along skid trails had better growth than those farther away, whereas trees near skips had poorer growth than those farther away (fig. 4). These spatial-position effects were not significant at Rail (fig. 4). Fresca had no previous thinning history; however, Rail had received a light thinning 11 years earlier; the recency of the earlier thinning at Rail may have reduced the treatment response. Certainly the general patterns of growth response at Rail between trees greater than or less than 10 m from a gap or skip are consistent with those observed at Fresca.

Where information is lacking concerning the effects of variable-density thinning on tree and stand growth, one option for managers is to estimate the proportion of stand area in each treatment category, predict the growth for that category, and sum the growth for the whole area. This approach assumes there are no effects associated with internal edges created by the thinning treatment. Based on the responses observed at Fresca, we predicted the estimation errors in basal area growth that might occur under three scenarios of patch sizes and relative stand proportions in skips or gaps. Given a scenario of 15 percent of the stand in 0.05-ha gaps and 10 percent of the stand in 0.5 ha skips, basal area growth within the thinned matrix would be underestimated by 13 percent. In a second scenario, if 25 percent of the stand was in 0.05-ha gaps and no skips were present, growth in the thinned matrix would be underestimated by 20 percent. In a third scenario of no gaps and 25 percent of the stand in 0.25-ha skips, growth in the thinned matrix would be overestimated by 5 percent. Thus, the magnitude of the over- or under-estimation of stand growth will depend on the spatial extent and distribution of the various thinning components.

Understory Vegetation

Understory vegetation increased in coverage in almost all treatments and subtreatments; that is, it increased in all four blocks where vegetation was measured from year 0 to 3, and again in the two blocks where vegetation as measured from year 3 to 7. The control plot at Bait was the only plot where coverage declined from year 0 to year 3. Although differences in sample size, protocols, and personnel may have increased variability in the vegetation data, we suspect that the main reason for the general increases in coverage were overstory crown damage associated with several widespread winter storms in western Washington. These storms would have broken branches and tops, thus, resulting in greater light reaching the understory. Four winter storms were recorded in 1996; this was prior to the implementation of any of the thinnings but would have affected understory

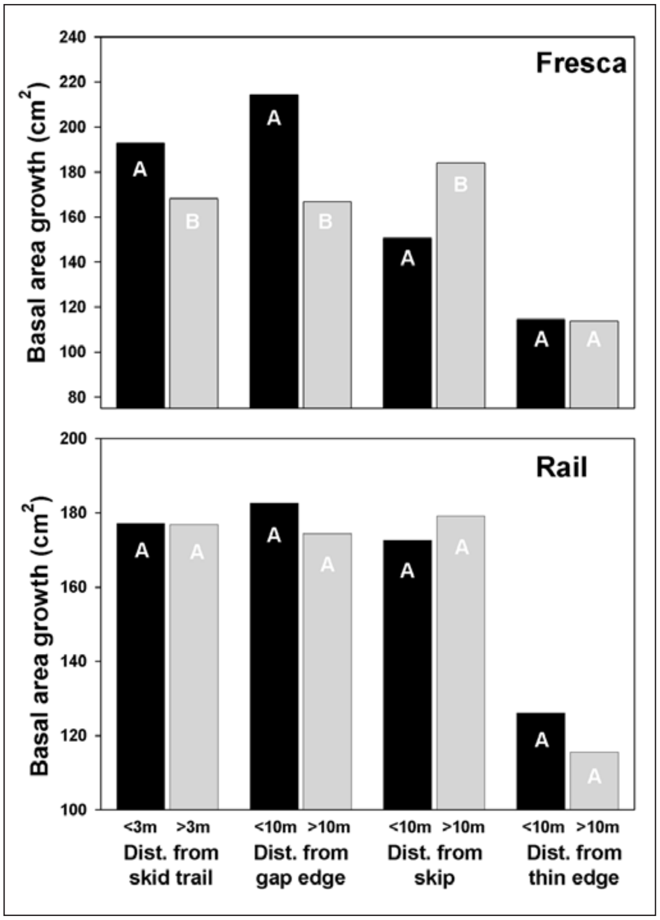

Figure 4—Mean basal area growth per tree by category indicating if trees were within 3 m of a skid trail, or within 10 m of a gap, an unthinned skip, or the thinned matrix. Paired bars with the same letters did not differ at p = 0.05.

response in the 1997 to 2000 time period (year 0 to year 3 for Fresca and Rail). Three other major snow and ice storms (in winter and spring 2002 and Jan 2004) could also have affected results between years 3 and 7 at Fresca and Rail.

In addition to the apparently weather-associated increases in understory coverage, the thinning also increased light to the understory and further enhanced understory development in the thinned matrix and the gaps (fig. 5). In the future, we would expect additional increases in the coverage of some species, especially in the gaps; however, if there is an extended period without major storms, crown closure will cause a reduction in percent coverage of some shade-intolerant species.

The pattern of the number of herbaceous species present was similar to the percentage of coverage. That is, there was a general overall increase from year 0 to 3 and again from year 3 to 7, and the greatest increase in number of

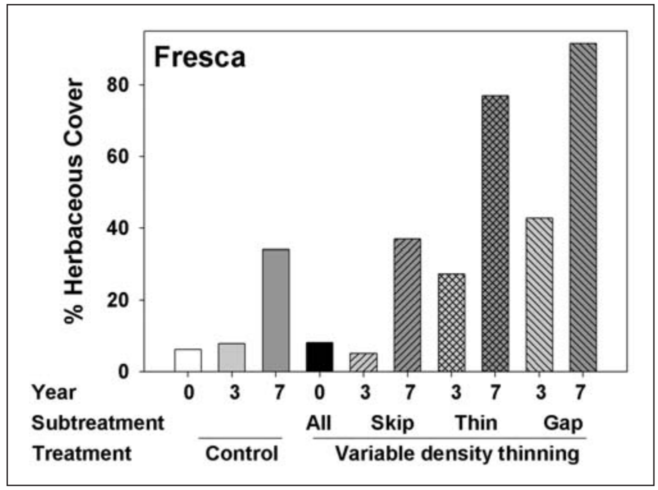

Figure 5—Percentage of cover of herbaceous species prior to thining and 3 and 7 years after thinning by treatment and subtreatment at Fresca.

species occurred within the more disturbed areas of the thinned plot. For example, the number of herbaceous species within the control plot at Fresca went from 12 to 14 within the first 7 years, whereas the number of species in the gaps of the variable-density thinning increased from 11 to 27 within the same period.

Introduced species were present at all sites and were more prevalent in the thinned and gap subtreatments than in the skips or control plots (fig. 6). All of the introduced species are herbaceous except one, *Rubus laciniatu*s, which is a shrub.

The response in the percent coverage of shrubs has been slower than that of herbaceous species and more variable over the four sites assessed. Stands with more initial shrub cover retained higher cover despite whatever damage was sustained in the winter storms or during the logging process, and coverage is generally increasing over time.

Percentage of cover of mosses and liverworts (fig. 7) was least at the one block measured on the east side of the peninsula (Snow White), possibly because this block receives significantly less annual precipitation than the other three blocks (table 1). Coverage of mosses and liverworts was greatest at all blocks in the undisturbed areas (control plots and skips).

Spatial distribution of herbaceous and shrub coverage differs in both control and variably thinned plots, but the rate of differentiation is greater in the thinned plots than in the control plot (fig. 8). The differentiation in the control plots reflects the changes in canopy cover (presumably due,

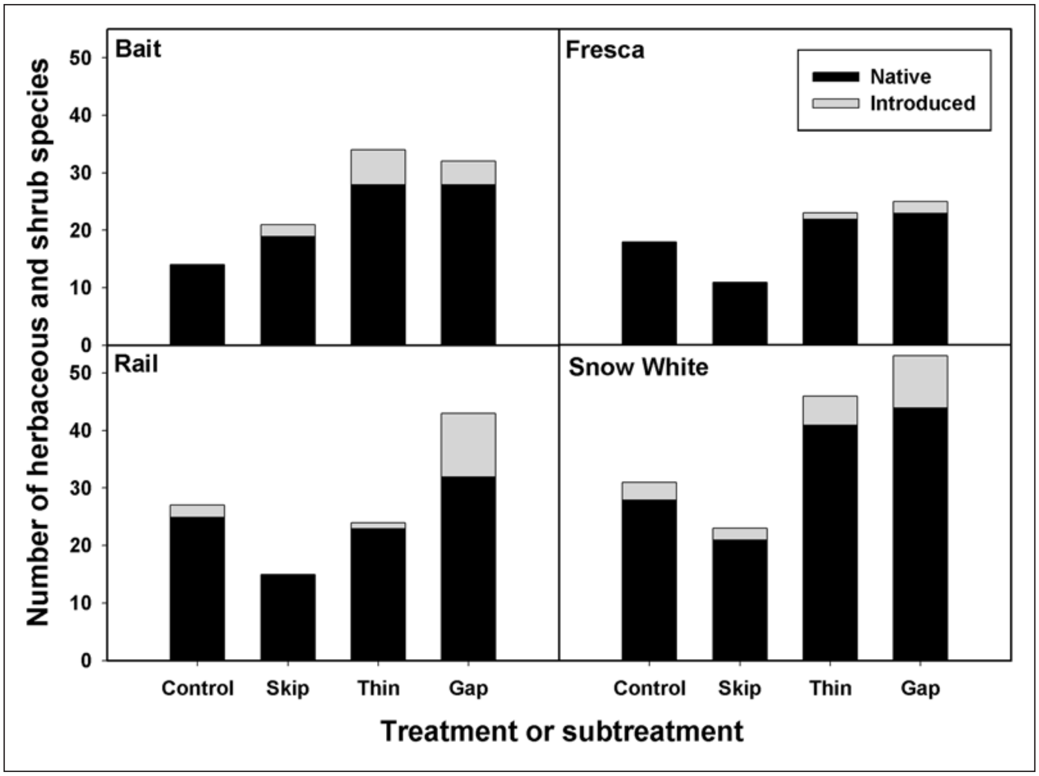

Figure 6—Number of native and introduced herbaceous and shrub species on control (unthinned) and variably thinned (skip, gap and thinned matrix) plots 3 years after thinning. The total number of species is divided into native and introduced species.

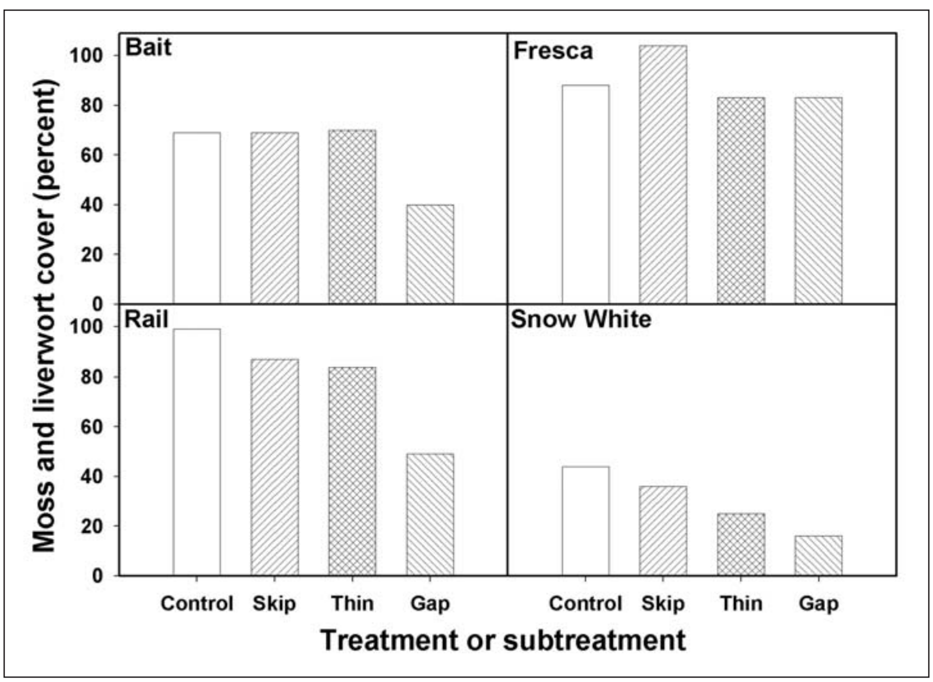

Figure 7—Percentage of cover of moss and liverworts 3 years after thinning by treatment and subtreatment at four blocks of the Olympic Habitat Development Study.

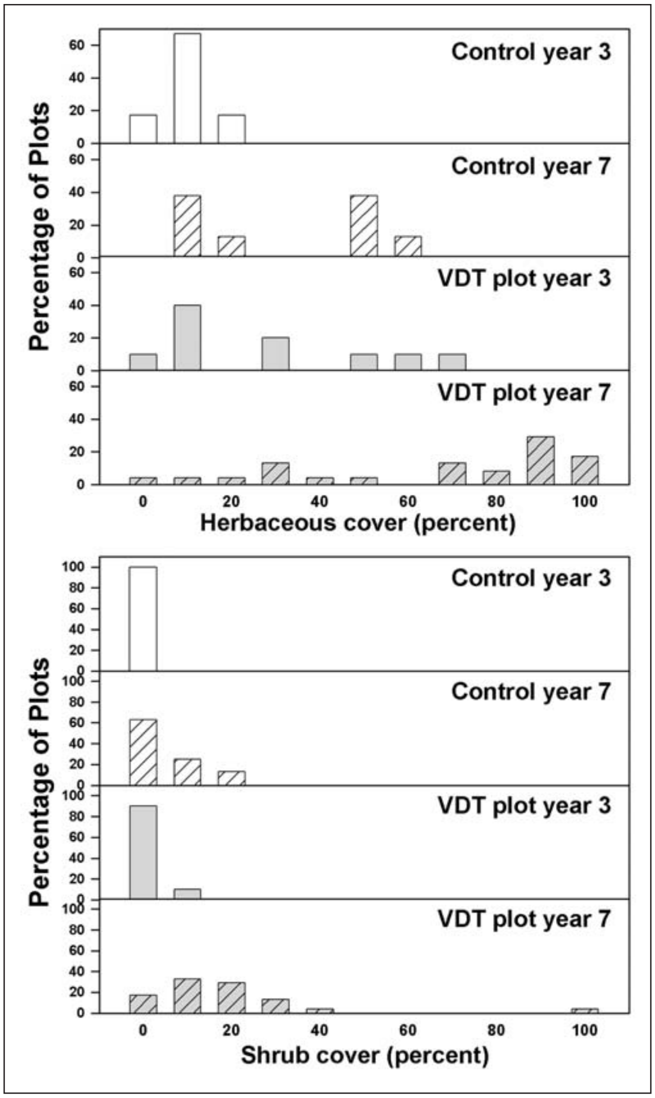

Figure 8—Change in distribution of herbaceous and shrub species cover on a control plot and variably thinned plot 3 to 7 years after treatment at Fresca.

in part, to crown damage associated with winter storms as discussed above) whereas the differentiation in the thinned plots reflects the much greater treatment-imposed variability in overstory cover.

Numbers of seedlings and saplings taller than 25 cm did not follow consistent patterns across the components of thinning at the four blocks (table 4). This may be due to natural variation or may reflect different stand histories at the four blocks. Stand densities at Bait and Fresca were high prior to thinning; thus, it makes sense that the most regeneration occurred in either gaps or the thinned matrix. The 1986 thinning at Rail (11 years prior to the variable-density thinning) resulted in substantial development of hemlock seedings throughout the area. Thus, the numbers for the skips at Rail represent 16 years of development of regeneration rather than 5. The variable-density thinning at Rail destroyed much of this advanced regeneration on a portion of the plot as seen by the much lower numbers for the gaps and thinned matrix. Snow White had been thinned between 1971 and 1973, and regeneration that developed following the earlier thinning had already grown into the understory and midstory strata and may have effectively precluded development of additional regeneration. Most regeneration on all four sites was western hemlock, but Douglas-fir, western redcedar, Sitka spruce, and cascara buckthorn (*Rhamnus purshiana* DC.) were also present.

MANAGEMENT IMPLICATIONS

There are many possible patterns and approaches to variable-density thinning prescriptions. The appropriate approach for use in a particular situation will depend on stand characteristics, landscape conditions, and management objectives. Thinning with skips and gaps is more complicated than some other prescriptions because there are three stand components to monitor. This type of prescription, which includes the maximum range of stand density from openings to unthinned patches, will likely result in greater heterogeneity than prescriptions that simply vary thinning intensity. No research is yet available to demonstrate whether the additional complexity is warranted for specific stand types or management objectives. We do know, however, that the prescription was easy for loggers to implement, and it did protect snags and other resources in the skips.

Early results from this study demonstrate that the variable-density thinning is increasing spatial heterogeneity in stand density and tree growth as well as heterogeneity in understory vegetation within the stands. Measurements from additional blocks as they develop following treatment, and long-term measurements on all blocks will help determine how universal the treatment responses are and how long they last. In addition, as a major rationale for the study was to examine treatment effects on wildlife habitat, future surveys should assess wildlife response. (In 2004, 8 of the original 36 plots were surveyed for the small mammals for the first time since treatment implementation.)

Future entries into these stands could remove additional overstory trees or possibly thin the developing understory. Possible future treatments might include rethinning the

Table 4—Density of regeneration taller than 25 cm at four blocks 5 years following variable-density thinning

Block	Skip	Thin	Gap	Treatment mean
		Number of trees per ha		
Bait	3,272	12,544	10,469	9,524
Fresca	9,903	1,924	17,118	7,357
Rail	149,353	73,021	60,243	90,623
Snow White	4,679	4,297	1,981	3,897

matrix; increasing gap size (for a subset of gaps); releasing (thinning around) individual overstory, midstory, or understory trees; and augmenting snags and large down wood. Managers should continue to try new methods, as it is unlikely a "one-size-fits all" variable-density thinning prescription will meet all objectives.

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Managing for Old-Growth Structure in Northern Hardwood Forests

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ABSTRACT

Recent research in the northeastern United States has focused on "structure-" or "disturbance-based" silviculture. The as yet untested hypothesis is that these approaches can sustain a broader array of biodiversity and ecosystem functions than conventional systems. I am testing this hypothesis using a system that promotes old-growth structural characteristics, termed "structural complexity enhancement" (SCE). This approach is compared against two conventional, uneven-aged systems (single-tree selection and group-selection) modified to enhance post-harvest structural retention. The study is replicated at two mature, northern hardwood forests in Vermont. Manipulations and controls were applied to 2-ha units. The uneven-aged treatments were replicated twice; the SCE treatment and controls were each replicated four times. Structural objectives include multi-layered canopies, elevated large snag and downed log densities, variable horizontal density, and reallocation of basal area to larger diameter classes. The latter objective is achieved by using an unconventional marking guide based on a rotated sigmoid target diameter distribution, applied as a nonconstant *q*-factor. The marking guide is also derived from a target basal area (34 m^2/ha) and maximum diameter at breast height (90 cm) indicative of old-growth structure. Crown release was also used to promote growth in larger trees. Prescriptions for enhancing snag and the density of downed woody debris are based on stand potential. Forest structure data, including Leaf Area Index (LAI), detailed measurements of individual trees, and coarse woody debris (snags and downed logs) densities and volumes, have been collected over 2 years pretreatment and 2 years post-treatment. A before/after/control/impact approach was used to analyze these data. Fifty-year simulations of stand development were run in NE-TWIGS, comparing alternate treatments and no-treatment scenarios. Basal area retention, relative density, canopy closure, LAI retention, and coarse woody debris volumes and densities were significantly higher under the old-growth silvicultural system. Residual diameter distributions achieved the target rotated sigmoid form. There will be significant differences in stand development based on the simulation modeling. Late-successional structural and compositional characteristics will develop to a greater degree under SCE. Large tree (>50 cm d.b.h.) recruitment will be impaired under the conventional treatments, whereas rates of large-tree development will be significantly accelerated under SCE.

KEYWORDS: Silviculture, old-growth, stand structure and development, northern hardwoods.

INTRODUCTION

Recent research on sustainable forestry practices in the northern hardwood region of the United States and Canada[2] has focused on "structure-" (Keeton et al. 2001) or "disturbance-based" (Seymour et al. 2002) silvicultural approaches. Structure-based forestry focuses on the architecture of forest stands in aggregate across the landscape or management units. Disturbance-based silviculture attempts to approximate the range of structural and compositional conditions associated with natural disturbance regimes. As complementary approaches, the shared operational objective

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[2] Includes all or portions of Minnesota, Wisconsin, Michigan, New York, Vermont, New Hampshire, and Maine in the United States, and Ontario, Quebec, New Brunswick, and Nova Scotia in Canada. Delineations sometimes also include portions of Pennsylvania and the southern New England states (Mladenoff and Pastor 1993).

is to explicitly manage for currently under-represented forest structures and age classes (Franklin et al. 2002) in densities and spatial configurations more similar to those associated with natural disturbance and successional dynamics (Seymour et al. 2002). In the northern forest region, this includes managing for late-successional structure, which is vastly under-represented relative to the historical range of variability (Cogbill 2000, Lorimer 2001, Mladenoff and Pastor 1993).

Particular interest in structure-based silvicultural approaches has evolved from studies of old-growth northern hardwood and mixed hardwood-conifer forests. These have demonstrated the ecological significance of specific structural elements, such as large trees (live and dead), downed logs, multi-layered canopies, and horizontal variations in stand density and gap mosaics (Dahir and Lorimer 1996, McGee et al. 1999, Tyrrell and Crow 1994b). These structures can be limited in forests managed under conventional even- and uneven-aged systems (McGee et al. 1999). Managing for late-successional forests has the potential to enhance ecosystem services associated with structural complexity, such as a subset of wildlife habitats, carbon storage, and riparian functions. As a result, managing for old-growth structural characteristics, either in part or in full, is a proposed alternative silvicultural approach (Keddy and Drummond 1996, Keeton et al. 2001, Mladenoff and Pastor 1993).

Although there has been much discussion of structure-based forestry in the theoretical literature, there have been few field trials or experimental tests in northern hardwood forests. An untested hypothesis is that silvicultural practices can accelerate rates of late-successional forest stand development (Franklin et al. 2002), promote desired structural characteristics, and enhance associated ecosystem functions more than conventional systems. I am testing this hypothesis using an approach termed "structural complexity enhancement" (SCE) that promotes old-growth structural characteristics while also providing opportunities for timber harvest (table 1). Structural complexity enhancement is compared against two conventional uneven-aged systems (single-tree selection and group-selection) that are advocated regionally for sustainable forestry (Mladenoff and Pastor 1993, Nyland 1998). Uneven-aged silvicultural systems are sometimes viewed as more ecologically desirable than even-aged systems because they maintain continuous forest cover, although the latter have applications for early-successional habitat management. Conventional uneven-aged prescriptions employed in this study are modified to increase post-harvest structural retention and to represent best available practices. In addition, group-selection treatments are modified to approximate the average size of canopy opening associated with fine-scale natural disturbance events in New England, based on the findings of Seymour et al. (2002).

The objectives for SCE are based on previous research describing old-growth northern hardwood and mixed northern hardwood-conifer forests (Goodburn and Lorimer 1998; Gore and Patterson 1985; McGee et al. 1999; Tyrrell and Crow 1994a, 1994b; Woods and Cogbill 1994; Ziegler 2000). They include multi-layered canopies, elevated large snag and downed log densities, variable horizontal density, and reallocation of basal area to larger diameter classes. The latter objective is achieved, in part, by using an unconventional marking guide based on a rotated sigmoid target diameter distribution. Rotated sigmoid diameter distributions have been widely discussed in the theoretical literature, but their silvicultural utility has not been field tested. Sigmoidal form is one of several possible distributions in eastern old-growth forests (Goodburn and Lorimer 1999; Leak 1996, 2002). These differ with disturbance history, species composition, and competitive dynamics. The distribution offers advantages for late-successional structural management because it allocates more growing space and basal area (and thus biomass and structures associated with larger trees) to larger size classes. I predict that this distribution is sustainable in terms of recruitment, growth, and yield. If so, it would support O'Hara's (1998) assertion that there are naturally occurring alternatives to the negative exponential or "reverse-J" curve typically used in uneven-aged forestry. It would also suggest that silviculturalists have greater flexibility in managing stand structure, biodiversity, and other ecosystem functions in the northern forest region than previously recognized.

METHODS

Experimental Design

The study is conducted at the Mount Mansfield State Forest and at the University of Vermont's Jericho Research Forest. These are located on the western slopes of the northern Green Mountain in Vermont. Study areas are mature, multi-aged, northern hardwood forests with minor shade-tolerant conifer components. There are three experimental manipulations. The first two are conventional uneven-aged systems (single-tree selection and group-selection) modified to enhance post-harvest structural retention. The modifications are based on a target residual basal area of 18.4 m^2/ha, max. diameter of 60 cm, and *q*-factor (the ratio of the number of trees in each successively larger size class)

Table 1—Structural objectives and the corresponding silvicultural techniques used to promote those attributes in structural complexity enhancement

Structural objective	Silvicultural technique
Multi-layered canopy	• Single tree selection using a target diameter distribution • Release advanced regeneration • Establish new cohort
Elevated large snag densities	• Girdling of selected medium to large sized, low vigor trees
Elevated downed woody debris densities and volume	• Felling and leaving, or • Pulling over and leaving
Variable horizontal density	• Harvest trees clustered around "release trees" • Variable-density marking
Reallocation of basal area to larger diameter classes	• Rotated sigmoid diameter distribution • High target basal area • Maximum target tree size set at 90 cm d.b.h.
Accelerated growth in largest trees	• Full and partial crown release of largest, healthiest trees

of 1.3. Group-selection cutting patches are each approximately 0.05 ha which results in 8 to 9 groups per treatment unit.

The third treatment is structural complexity enhancement (SCE). The marking guide (the number of trees that must be cut in each size class to achieve the desired post-harvest structure) is based on a rotated sigmoid (see Leak 2002) target diameter distribution (number of trees per size class). This is applied as a nonconstant *q*-factor: 2.0 in the smallest sizes classes, 1.1 for medium-sized trees, and 1.3 in the largest size classes. The marking guide is also derived from a target (desired future condition) basal area (34 m^2/ha.) and maximum diameter at breast height (90 cm) indicative of old-growth structure. Accelerated growth in larger trees is promoted through full (4- or 3-sided) and partial (2-sided) crown release. Prescriptions for enhancing coarse woody debris (CWD) volume and density are based on stand potential (e.g., preharvest CWD volume) and literature-derived targets. Snags were created by girdling diseased, dying, or poorly formed trees. Pretreatment densities of low vigor trees were sufficient such that girdling of healthy trees was not necessary to achieve snag prescriptions. On one SCE unit at each of the two study areas, downed logs are created by pulling trees over, rather than felling, to create pits and exposed root wads.

Each of the first two treatments (uneven-aged) is replicated twice at Mount Mansfield; the third (SCE) is replicated four times, twice at each of the two study areas. Two unmanipulated control units are located at each study area. Treatment units are 2 ha and separated by 50 m (minimum) unlogged buffers to minimize cross contamination of treatment effects. Experimental manipulations (i.e. logging) were conducted on frozen ground in winter (January through February) 2003.

Data Collection

There are five, randomly placed, 0.1-ha permanent sampling plots in each treatment unit. Within each plot, all live and dead trees > 5 cm d.b.h. and > 1.37 m tall were permanently tagged, measured, and recorded by species, diameter, height, and decay stage. Tree heights, height to crown base, and average crown width on each tagged tree were measured using an Impulse 200 laser range finder. Downed log (logs > 10 cm diameter) volume by decay class (1-5) was estimated using a line intercept method, and densities were measured across 0.1-ha plots. Leaf Area Index (LAI) was measured at five points in each plot using a Li-Cor 2000 meter. Two dominant canopy trees per plot were cored at breast height to allow subsequent laboratory determination of tree age and site $index_{50}$. Two years of pretreatment and 2 years of post-treatment data collection have been completed.

Data Analysis

The Northeast Decision Model (NED) (Simpson et al. 1996) was used to generate stand inventory metrics based on pre- and post-harvest sample data. NED data were exported to NED-SIPS (Stand Inventory and Processing System) for stand development simulation using the NE-TWIGS model (northeastern U.S. variant of TWIGS), an individual tree-based, distance-dependent stand growth simulator (Hilt and Teck 1989). Fifty-year projections of stand development were run for each treatment unit, including controls, using both pre- and post-harvest scenarios. Cumulative basal area increment (CBAI) was calculated for each simulation run at 5-year intervals. Projections were normalized by calculating the differences in CBAI between no-harvest and harvest scenarios at each time step. The Kolmogorov-Smirnov two-sample goodness of fit test was used to test for differences between treatment groups along mean CBAI time series. Single-tree selection and group-selection treatments were classified as one group (conventional uneven-aged aged) for the purposes of these tests. This was appropriate because there were no significant differences among uneven-aged units in residual stand structure when data were aggregated to the unit scale. The log-likelihood ratio goodness of fit test (*G* test) was used to examine total CBAI developed after 50 years; response ratios (treatment vs. no treatment) were compared against a null ratio (no treatment effect). NE-TWIGS was also used to predict the number of large trees (two classes: > 50 cm and > 61 cm d.b.h.) developed after 50 years. Sample data, including individual tree heights, crown dimensions, and CWD attributes, were also used as input for 3-dimensional modeling in the Stand Visualization System (SVS) (McGaughey 1997).

A before/after/control/impact (Krebs 1999) statistical approach was used to compare preharvest and residual stand structure. Statistical analyses of structural variables included tests of means (e.g., ANOVA, Bonferroni multiple comparisons, *t* tests) and tests of variance (e.g., *F* tests). The latter were used to test equal variance assumptions. For three-way comparisons of residual structure at Mount Mansfield alone, plots were aggregated by treatment type rather than experimental unit. The sampling frame was defined as the continuous population of forest patches rather than arbitrarily imposed unit delineations (Stehman and Overton 1996). *F* tests of variance were used to evaluate consistency in post-harvest structure among units treated with the same prescription. To validate the use of plots as independent samples, spatial autocorrelation tests (Riply 1981) using the Moran coefficient (Moran 1950) were performed on relevant response variables using S-Plus statistical software (Kaluzny et al. 1998). Response data were sorted by treatment and made spatially explicit using georeferenced plot positions. Spatial autocorrelation results were cross-checked against empirical variograms produced in S-Plus.

Diameter distributions (pre- and post-harvest) are a useful indicator that integrates vertical and horizontal structural responses to treatment. To determine whether SCE successfully shifted diameter distributions toward the target rotated sigmoid form, pre- and post-harvest and target distributions were log transformed to enhance sigmoidal tendencies (Leak 2002). Residual distributions were smoothed by using a Friedman smoothing run in S-Plus software. Kolmogorov-Smirnov two-sample goodness of fit tests were used to test for statistically significant differences between transformed residual and target cumulative frequency distributions. Residual distributions were created by using real (sample) data for smaller diameter classes (<70 cm d.b.h.) and hypothetical (e.g., future potential) values for larger diameter classes (>70 cm d.b.h.). The latter borrowed values from the target distribution. Statistical tests, therefore, evaluated whether residual distributions achieved that portion of the target distribution possible given the preharvest structure.

RESULTS

Residual Stand Structure

Visualizations generated in SVS illustrate the high degree of structural complexity maintained by both SCE and single-tree selection (fig. 1). High levels of residual structure were maintained by all of the experimental treatments, including group selection. However, there were distinct differences. Canopy closure was highest for SCE (mean 77 percent) and lowest for single-tree selection units (mean 64 percent). These results were statistically significant ($P < 0.01$). Canopy closure, as expected, was most variable across group-selection units. Aggregate canopy closure remained high in group-selection units because 70 to 80 percent of each group-selection unit was unlogged and thus maintained full preharvest structure. For investigations focused on Mount Mansfield, *F* tests of variance showed no significant differences ($a = 0.05$) in post-harvest structure between similarly treated units. There was no significant ($a = 0.05$) spatial autocorrelation among plots sorted by treatment; a result confirmed by empirical variograms. Individual plots were determined to be spatially independent samples based on these results.

There were significant differences ($P < 0.001$) in LAI responses among treatments. Single-tree and group selection cuts reduced LAI by 20 and 30 percent respectively. LAI reductions were lowest in SCE units (9 percent), indicating high retention of foliage bearing tree crowns and thus, by inference, vertical complexity. LAI was significantly more spatially variable for both SCE ($P = 0.031$) and group-selection ($P = 0.010$) compared to single tree selection; within-treatment variance was not significantly different between SCE and group-selection units ($P = 0.296$). These results are indicative of the high degree of

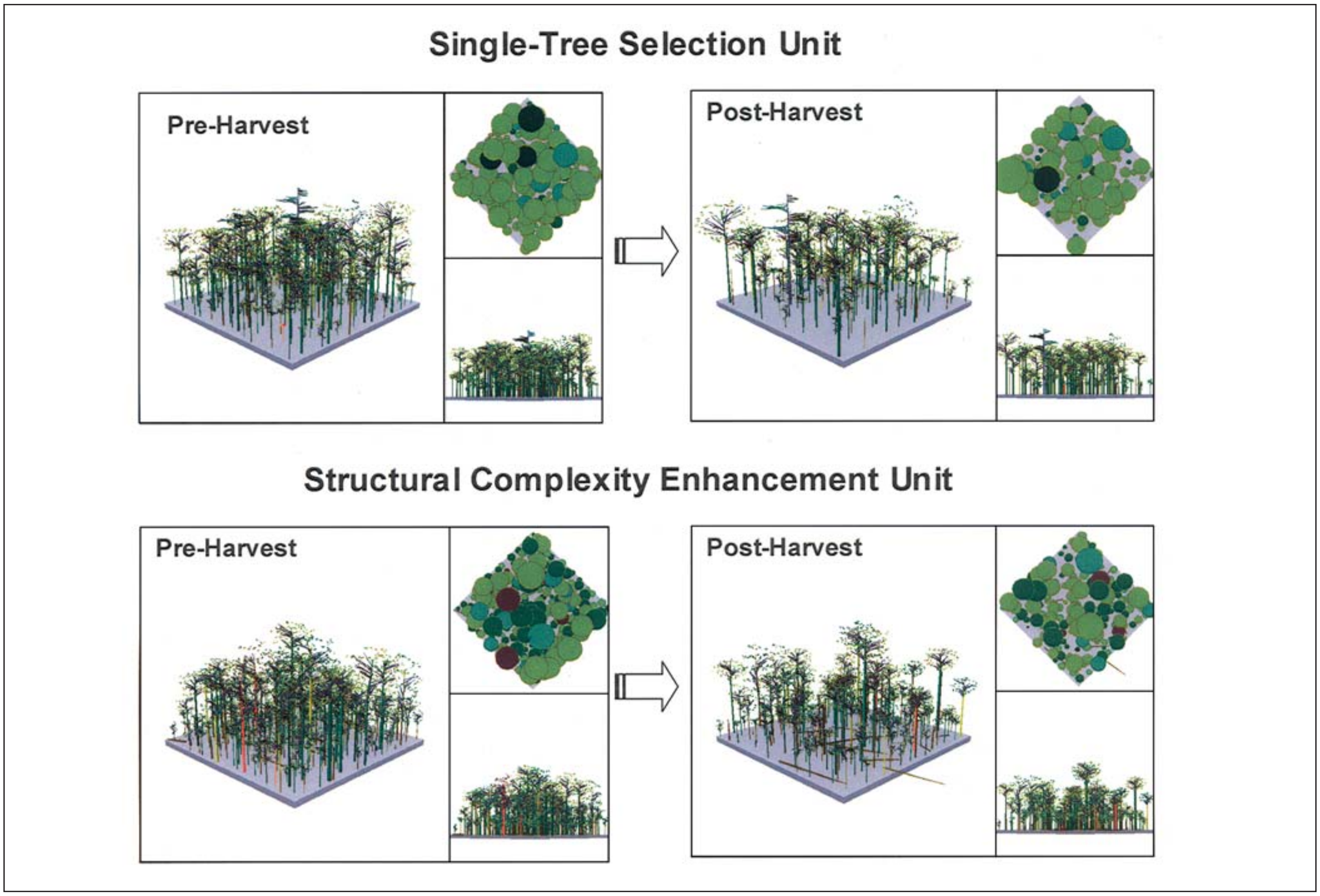

Figure 1—Output of the Stand Visualization System (SVS) contrasting single-tree selection in unit 4 (above) with structural complexity enhancement (SCE) in unit 2 (below) at the Mount Mansfield study area. Images of pre- and post-harvest stand structure for 1-ha blocks are shown. Shaded circles represent tree crowns (with species-specific coloration) seen from a simulated aerial view. Note the high degree of post-harvest structure (e.g., basal area and stem density), canopy closure, vertical complexity, and downed log densities in the SCE unit. Note the similar, though lower, degree of structural retention in the single-tree selection unit.

horizontal structural variability expected for group selection. In SCE units, increased horizontal complexity was achieved through variable-density marking and clustered harvesting around crown-release trees.

A significantly higher level of residual basal area was maintained by SCE compared to either single tree selection (P = 0.047) or group selection (P = 0.041) units using aggregated, spatially independent plot data (n = 10 per treatment) for Mount Mansfield only. Post-harvest relative density was also significantly greater in SCE units compared to single-tree selection (P = 0.013); it was not significantly greater than group-selection units (P = 0.123). There were no statistically significant differences (a = 0.05) in variance within groups of plots aggregated by treatment. This result held for both pre- and post-harvest structure.

SCE shifted residual diameter distributions to a form indistinguishable from the target rotated sigmoid form. There were no statistically significant differences (a = 0.05) between residual and target distributions for any of the SCE units based on the goodness of fit test using log transformed diameter distributions (fig. 2). Future continued reallocations of basal area and stem density into larger size classes, yielding a rotated sigmoid distribution spanning a full range of diameter classes, are thus likely.

Crown Release and Vertical Development

Variable density harvesting resulted in crown release for 45 dominant trees per ha on average in SCE units. When combined with the average pretreatment number (20 per ha) of large trees (> 50 cm d.b.h.), our future target of 55 large trees per ha is exceeded. The excess provides a margin

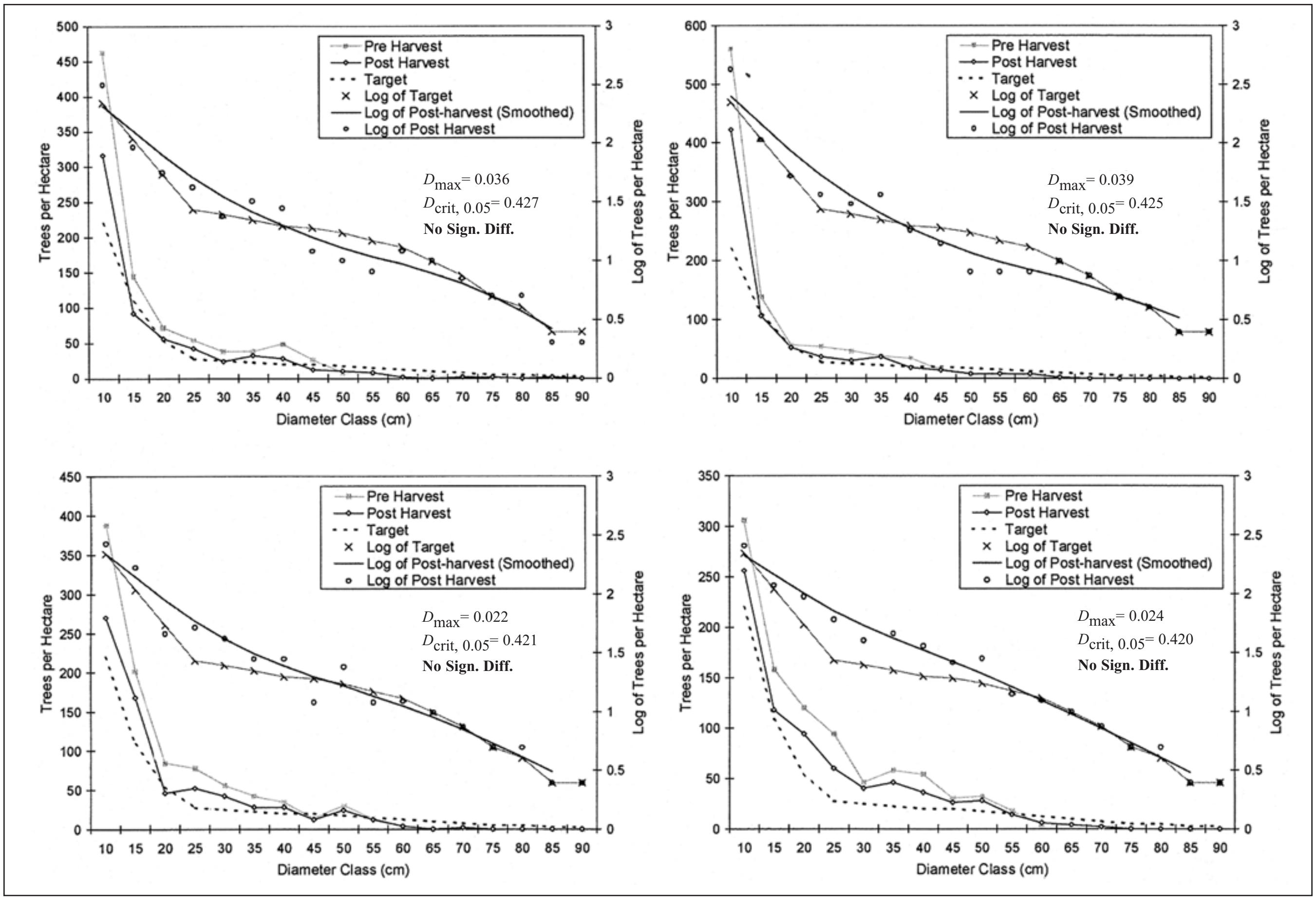

Figure 2—Preharvest, post-harvest, and target diameter distributions for the four units subject to the structural complexity enhancement treatment, two at Mount Mansfield (top) and two at the University of Vermont's Jericho Research Forest (bottom). Log transformed post-harvest and target distributions are compared (top portion of graphs) by using the Kolmogorov-Smirnov two-sample goodness of fit test. There were no statistically significant differences. Thus, the post-harvest distributions achieved the target rotated sigmoid distribution.

of safety to accommodate canopy mortality. Crown release is likely to accelerate growth rates in the affected dominant trees by 50 percent or more based on previous modeling (e.g. Singer and Lorimer 1997). Dominant canopy trees were released across a range of diameter classes (>25 cm d.b.h.); the majority were fully, rather than partially, crown released. Crown release also resulted in spatial aggregations of harvested trees, creating canopy openings and variable tree densities. Elevated light availability associated with clustered harvesting around crown release trees is likely to promote vertical differentiation of the canopy through release and regeneration effects. This will increase foliage density in the emergent and lower canopy layers over time.

Coarse Woody Debris Enhancement

Prescriptions to enhance structural complexity resulted in substantially elevated densities of both downed logs and standing snags. The structural complexity enhancement treatments increased CWD densities by 10 boles (> 30 cm d.b.h.) per ha on average for snags and 12 boles (> 30 cm d.b.h.) per ha on average for downed logs. Pulling trees over, in most cases, successfully created large, exposed root wads and pits. There were statistically significant differences ($P = 0.002$) among treatments with respect to downed log recruitment effects (fig. 3). Post-harvest downed log volumes were 140 percent higher on average than preharvest levels in SCE units. Mean downed log volume increased 30 percent in the combined uneven-aged units, although this effect was not statistically significant relative to the controls. There were only slight (5-percent mean) increases in control units due to natural mortality; volumes declined in some control units. Background recruitment rates were thus not sufficient to explain SCE treatment effects. Analyses of downed log decay class distributions in SCE units showed, as expected, significant ($P < 0.05$) shifts towards less decayed logs due to large inputs of felled trees.

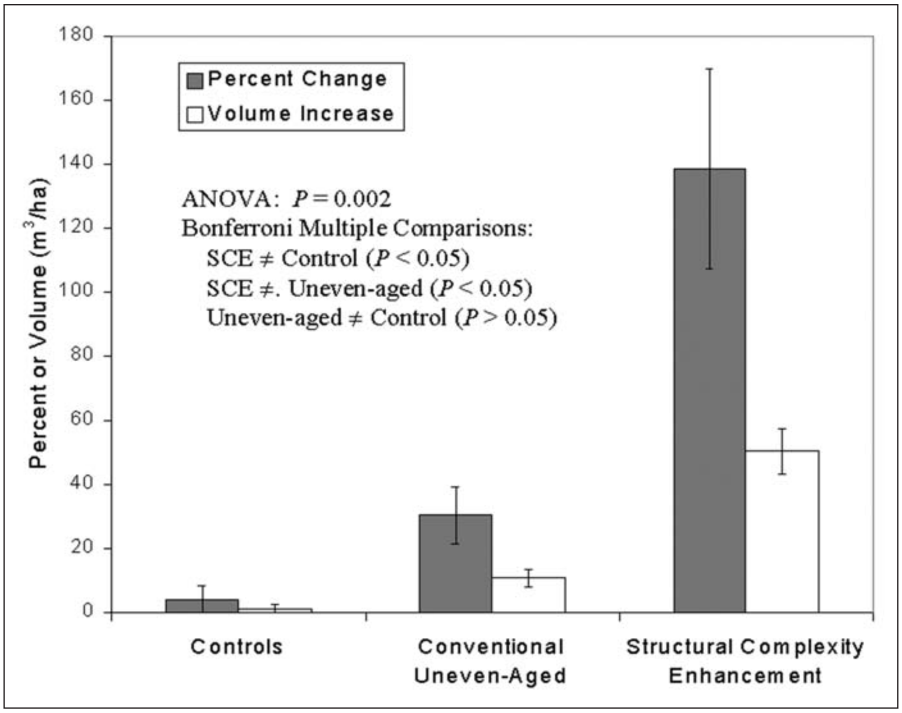

Figure 3—Downed log response to treatments. Shown are percentage of change from preharvest levels and absolute change in volume (m^3/ha). Error bars are ±1 standard error of the mean.

Projected Stand Development

Stand development projections suggest that total basal area under SCE will, on average, approach 34 m^2/ha after 50 years of development. This is >50 percent higher than the mean for the conventional uneven-aged units. However, this difference is attributable to the higher residual basal area left by SCE. The projections showed no significant differences in absolute growth rates between treatment scenarios, as measured by cumulative basal area increment (CBAI) (fig. 4, top). When projected developed with treatment is normalized to reflect the amount of development (specific to each unit) that would have been expected with no treatment, the simulations indicate that CBAI will be faster under conventional systems (fig. 4, bottom). Both SCE ($P < 0.05$) and conventional treatments ($P < 0.01$) are projected to significantly accelerate tree growth rates above that expected with no treatment based on NE-TWIGS modeling. Total projected CBAI after 50 years was 12.5 m^2/ha (no treatment) compared to 28.0 m^2/ha (with treatment), on average, in SCE units. For conventional units, total mean projected CBAI increased from 1.5 m^2/ha (no treatment) to 23 m^2/ha (with treatment).

SCE is projected to significantly enhance rates of large tree recruitment over no-treatment scenarios. There will be an average of 17 more large trees (> 50 cm d.b.h.) per ha than there would have been without treatment after 50 years in SCE units. There will be 29 fewer large trees per ha on average in the conventional units than would have developed in the absence of timber harvesting (fig. 5).

DISCUSSION

Silvicultural techniques can be used effectively to promote old-growth structural characteristics in northern hardwood and mixed northern hardwood-conifer forests. Both the uneven-aged approaches tested and SCE maintain high levels of post-harvest structure and canopy cover. However, SCE maintains, enhances, or accelerates development of CWD, canopy layering, overstory biomass, large tree recruitment, and other structural attributes to a greater degree. The higher levels of structural retention associated with SCE are indicative of lower intensity, minimal impact forestry practices.

Both SCE and conventional uneven-aged treatments will result in accelerated tree growth rates according to simulation projections. Because the conventional treatments retained less basal area, their comparatively higher projected basal area increment is consistent with previous research on growth responses to stocking density (Leak et al. 1987). Note, however, that the NE-TWIGS model is not spatially

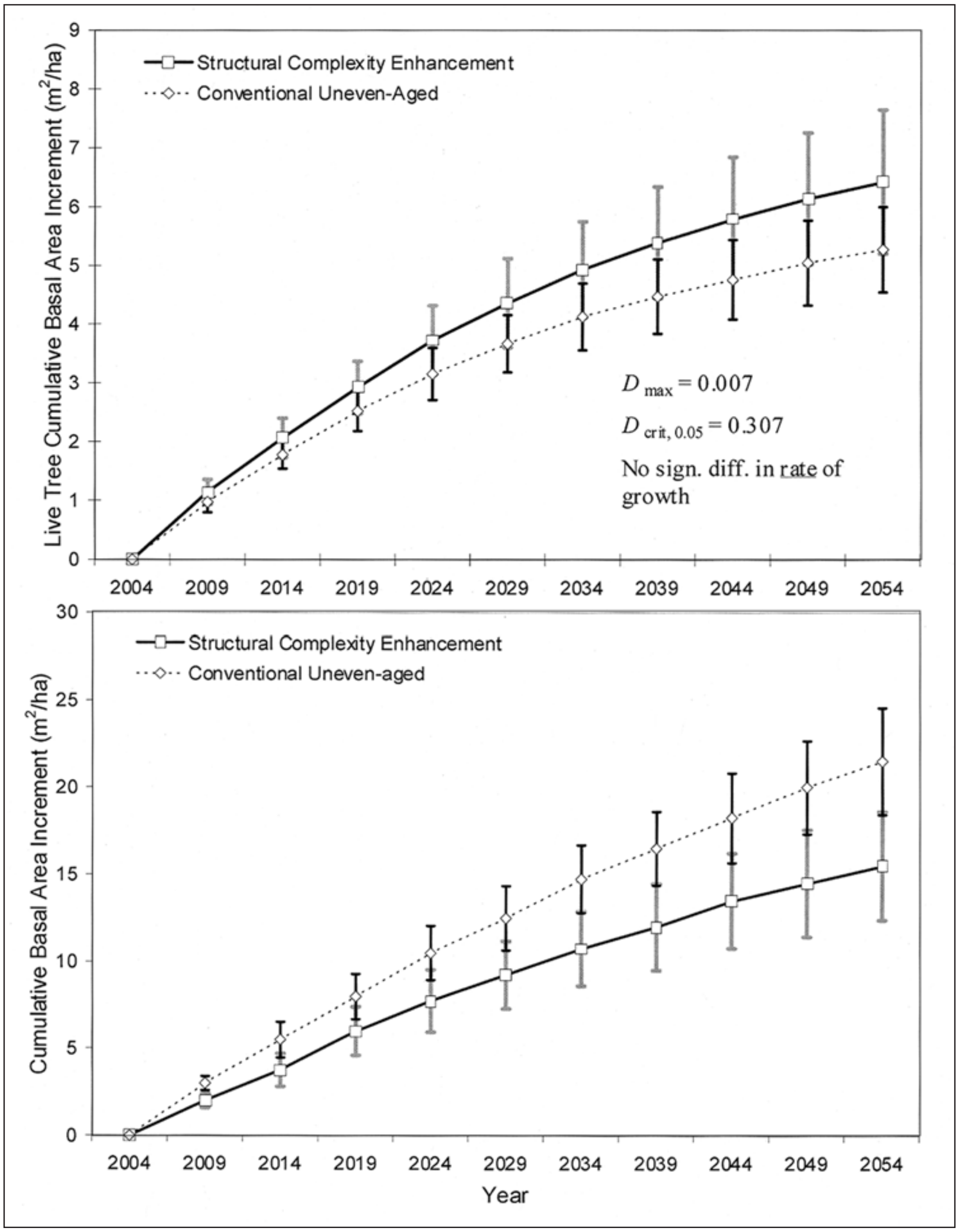

Figure 4—Results of NE-TWIGS stand development modeling. Shown are cumulative basal area increment (CBAI, live tree) for 50-year projections of post-harvest structure (top) and normalized scenarios (post-harvest minus preharvest CBAI). Error bars are ±1 standard error of the mean.

explicit. Inter-stem competition and tree growth rates are simulated as a function only of total stand stocking (within size classes) and not the spatial position of individual trees. The model does not, therefore, capture the effects of crown release employed in SCE. Because crown release is likely to significantly increase growth rates in selected dominant trees (Singer and Lorimer 1997), spatially explicit simulation modeling may result in different, and possibly enhanced, developmental projections for SCE. Regardless, an important effect of SCE is the promotion of large-tree recruitment; this process is impaired under conventional treatments that include maximum diameter limits. Projected basal area is also higher after 50 years of development under SCE due to elevated post-harvest structural retention.

Structural complexity enhancement resulted in significantly elevated CWD densities and volumes. However, it remains uncertain whether this effect will persist until natural

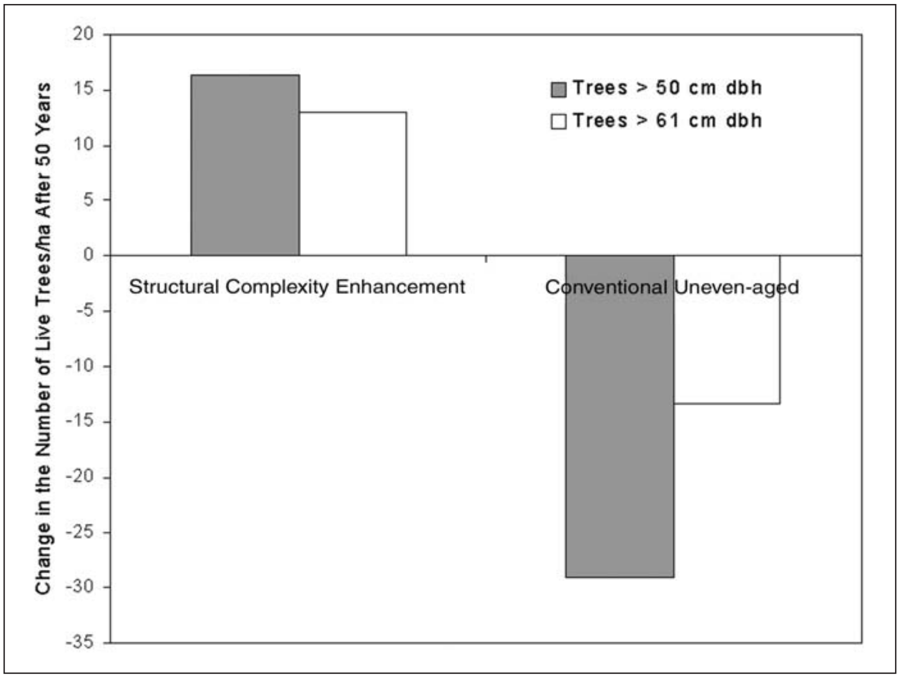

Figure 5—Projected change in large tree densities after 50 years. Values represent the difference between treatment and no-treatment scenarios. Note the increased recruitment of large trees under SCE versus the impairment of large tree recruitment under the conventional uneven-aged treatments.

recruitment rates increase, or, alternatively, whether CWD enhancement in mature stands has only transient or short-term management applications. Although long-term CWD persistence and accumulation dynamics are uncertain, it is likely that decay-class distributions will again shift over time toward better decayed material. This would render silviculturally-enhanced CWD more biologically available in habitat and nutrient processes in the future (Goodburn and Lorimer 1998, Gore and Patterson 1985, Tyrrell and Crow 1994a).

SCE may have several useful applications, depending on economic feasibility, ranging from old-growth restoration, to riparian management, to low-intensity timber management, and late-successional wildlife-habitat enhancement. Depending on the specific application, SCE could be employed to varying degrees. For instance, where timber production is emphasized, a subset of SCE elements might be used. Other elements might be avoided or employed at a lesser intensity. In this scenario, multiple stand entries would be expected, but late-successional structural development would be lower compared to full SCE implementation. Such an approach, however, would allow forest managers to build some degree of old-growth associated structure into actively managed stands, while maintaining greater flexibility in timber management. Managers of protected areas, conversely, might choose to employ SCE more fully. They might enter a stand once or twice, thereafter allowing accelerated successional processes to take over. The degree of implementation and the number of stand entries will differ by application.

Forest managers have the flexibility to manage for a wide range of structural characteristics and associated ecosystem functions. Uneven-aged systems provide some, but not all, late-successional structural characteristics, or provide them to a more limited extent. Residual basal area, maximum diameter, and *q*-factor can be modified singly or collectively, resulting in greater structural retention. However, maximum diameter limits significantly retard the potential for large tree (live and dead) recruitment based on the results. Stand development is thus continuously truncated by multiple uneven-aged cutting rotations or entries. The results show that SCE's variable *q*-factor marking guide can be used to successfully achieve a rotated sigmoid diameter distribution. Unconventional prescriptive diameter distributions, such as the rotated sigmoid, combined with higher levels of residual basal area, very large (or no) maximum diameters, and crown release are other alternatives for retaining high levels of post-harvest structure and for accelerating stand development.

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Evaluation of Silvicultural Options for Harvesting Douglas-fir Young-Growth Production Forests

David D. Marshall[1] and Robert O. Curtis[2]

ABSTRACT

This report summarizes data from establishment of the Blue Ridge and Copper Ridge installations and 5-year growth information from Blue Ridge, which are part of the Silvicultural Options for Young-Growth Douglas-fir Forests study on the Capitol State Forest near Olympia, Washington. Six silvicultural regimes are compared: clearcut, two-age, patch cut, group selection, continued thinning on an extended rotation, and untreated control. The study aims to create widely different stand conditions and to evaluate them from the standpoints of timber production, costs, visual effects, and public acceptance. It is a cooperative effort of the Pacific Northwest Research Station of the USDA Forest Service, Washington Department of Natural Resources, University of Washington, University of Idaho and Oregon State University.

KEYWORDS: Silvicultural systems, multiple use, visual effects, landscape management, *Pseudotsuga menziesii*.

INTRODUCTION

The great productivity of the maritime forests of the Pacific Northwest has long been recognized. Beginning in the mid-1800s, its large inventory of untouched timber provided the basis for establishment and development of a large timber industry that was a major contributor to development of the region. Until quite recently timber production was the major objective on most federal and private land in the region. Fire protection, roads, improved harvesting systems, improved regeneration systems, and strong markets all favored more intensive silviculture. Investments in managing stands and increased growth rates pushed rotation ages down. By the 1980s, many landscapes in the region were dominated by clearcuts and young plantations. The result was that timber production was often seen in direct conflict with other forest values (habitat, visuals and watersheds).

With the increase in public concern and involvement, many public forestland managers are looking for alternatives to the traditional and visually objectionable clearcut. While the region has gained great experience with even-aged silvicultural systems since the 1940s, there has been very little investigation of alternatives (Curtis 1998). Although much existing knowledge can provide guidance in developing possible management strategies for multiple objectives (Curtis et al. 1998), there have been only limited (and often poorly designed) tests of alternatives to traditional clearcutting, and managers have little experience with potential alternatives.

As a result of public concerns, forest managers of the Washington State Department of Natural Resources (DNR) began trying harvesting alternatives to clearcutting in the early 1990s. They soon recognized the need for quantitative evaluation of results of possible alternatives to guide their management decisions. They turned to the scientists of the Silviculture and Forest Models team of the USDA Forest Service's Pacific Northwest Research Station (PNW). Together, the land managers of the DNR and scientists of the PNW developed and implemented the Silvicultural Options for Young-Growth Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) Forests study.

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METHODS

Study Objectives

The Silvicultural Options for Young-Growth Douglas-fir Forests study is intended to provide comparisons of silvicultural regimes that will have long-term value for research and demonstration. The regimes included were selected to represent a continuum of forest cover (removed and retained) and disturbance (intensity and frequency). Each regime was considered biologically and operationally feasible and one that could be implemented as part of a managed, sustainable forest landscape to provide different levels and mix of financial returns, wood production and nontimber values.

Specific objectives are to

- Create on-the-ground examples of contrasting silvicultural regimes that can be evaluated for effectiveness in reducing visual and other environmental impacts of forestry operations while providing high timber outputs over time.
- Monitor development of stands under these regimes over time in a manner that provides quantitative estimates of change, outputs, and costs and allows statistically valid tests of differences between regimes.

Specific studies that have been implemented to date include monitoring residual tree growth, damage and mortality; stand development and yields; costs of harvesting and stand tending; harvesting production; soil disturbance impacts; visual quality and public response; and song bird populations. The wide range of studies has required a cooperative approach that includes scientists from the Pacific Northwest Research Station, Washington State Department of Natural Resources, University of Washington, University of Idaho and Oregon State University.

Study Design

The study is a randomized block experiment with six treatments and three replications. The treatments are assigned randomly and applied to units of 10 to 30 ha each. Curtis et al. (1998) present the rationale for the treatments selected. The six treatments applied are

1. **Clearcut** – a conventional even-aged system that has been widely applied in the Douglas-fir region of Oregon, Washington, and British Columbia that removes nearly 100 percent of trees and is regenerated by replanting. It is included to provide direct quantitative comparisons of costs and outputs with the other treatment regimes.
2. **Two-Age** – a two-aged system that retains about 40 evenly spaced, vigorous trees per ha in the overstory and establishes a second age-class of trees in the understory by planting. Initially this treatment resembles a shelterwood treatment; however, the overstory trees will be carried through the second rotation to provide partial forest cover and future large, high-quality trees.
3. **Patch Cut** – an uneven-aged mosaic of even-aged patches created by periodically (15-year cycle) harvesting 20 percent of the area in small patch cuts ranging in size from 0.6 to 2.0 hectares (ha). Patches are planted and the areas surrounding the patches are thinned as needed to maintain vigorous growth. This treatment avoids large harvest areas like the clearcut, but allows for individual patches to be treated with well-developed, even-aged methods. The lower limit of patch size was adopted to provide an adequate light regime for Douglas-fir and minimize future damage to the surrounding stand from harvesting. Over time the area will be converted to an uneven-aged mosaic of even-aged patches.
4. **Group Selection** – an uneven-aged system in which 20 percent of the area is harvested at 15-year intervals in small groups of trees that create openings from approximately 0.02 ha up to 0.6 ha and distributed randomly throughout the stand. Openings greater than 0.04 ha are planted and the areas surrounding the groups are thinned as needed to maintain vigorous growth. This regime resembles the patch cut treatment, but with the opening sizes not exceeding 0.6 ha. This was chosen because it may reduce visual impacts, yet it is expected to have higher harvest and management costs and may favor more light tolerant species over Douglas-fir.
5. **Extended Rotation with Commercial Thinning** – a typical thinning from below that targets removal of about one fourth of the basal area throughout the stand. Unlike the first four treatments that initiate Douglas-fir regeneration, thinning defers the regeneration harvest and takes advantage of the ability of thinned Douglas-fir to maintain high growth rates while producing some revenue and reducing the land area in the visually obtrusive regeneration stage of stand development. Regeneration of the next generation of trees in this regime could eventually be done by any one of the above methods.
6. **Extended Rotation without Thinning (Control)** – this treatment also defers a regeneration harvest, but unlike the commercial thinning treatment, no trees are removed.

Figure 1—Aerial photo after 2002 harvest of the Copper Ridge site showing locations of treatment regimes (photo area is about 4 km wide).

Table 1—Summary of three installations of the Silvicultural Options for Young-Growth Douglas-fir Forests study

Installation	Harvest year	Harvesting system	Total area (ha)	Stand origin	Stand age (years)	Site index[a] (meters)
Blue Ridge	1998	Ground	105	Natural	70	39
Copper Ridge	2002	Cable	109	Natural	69	30-39
Rusty Ridge[b]	2004	Ground	89	Planted	49	37

[a] Site index is at age 50 (breast height).

[b] Rusty Ridge age and site index is based on preharvest stand exam data.

This is another option, like thinning, for adjusting unbalanced age distributions by carrying stands to longer ages and for reducing visual impacts of regeneration harvesting on the landscape.

All of the study sites are located on the Capitol State Forest, southwest of Olympia in western Washington (lat 46.85° N, long 123.15° W). The Washington State DNR manages this forest and applied treatments as part of their operational timber sales program which meets all forest practices requirements. The three replications are Blue Ridge (harvested in 1998), Copper Ridge (harvested in 2002) and Rusty Ridge (harvested in 2004). Figure 1 shows the Copper Ridge site after the initial harvest. All the units represent productive site of mostly Douglas-fir sites but differ in age and harvesting requirements (table 1). The Blue Ridge and Copper Ridge sites are older and originated after harvesting and fire whereas the Rusty Ridge site is younger and originated from planting after harvest. The range in stand characteristics created in this experiment will provide operational experience for managers implementing these regimes in a range of conditions and using different harvesting methods.

For assessment of tree growth and stand development, a grid of permanent sample plots has been established in each treatment unit. The number of plots in a treatment ranges from 15 to 38 depending on the expected variability. Each sample plot consists of 3 nested fixed area subplots: a 0.08 ha plot for trees greater than 24.4 cm diameter at breast height (d.bh., measured 1.37 m above the ground), a 0.04 ha plot for trees greater than 14.0 cm and up to 24.4 cm d.bh., and a 0.01 ha plot for trees from 4.0 cm up to 14.0 cm d.b.h. Regeneration (trees less than 4 cm d.b.h.) and low-ground vegetation are assessed on four satellite plots (nested 0.002 ha and 0.01 ha sized plots respectively) each centered at 16.1 m in cardinal directions from the main plot center. All trees in the plots are identified by species and measured for d.b.h. with heights and height-to-crown-base sampled. Low-ground vegetation is characterized by height and cover for species groups. Studies by Bradley et al. (2004), Reutebuch et al. (2004) and Wilson (2004) are also referenced to this plot grid.

RECENT FINDINGS

Curtis et al. (2004) have reported results from the establishment of the first installation (Blue Ridge) in 1998. Since 1998, the two other installations have been, or are in the process of being harvested, and the Blue Ridge site has had a 5-year remeasurement. Although certain questions can

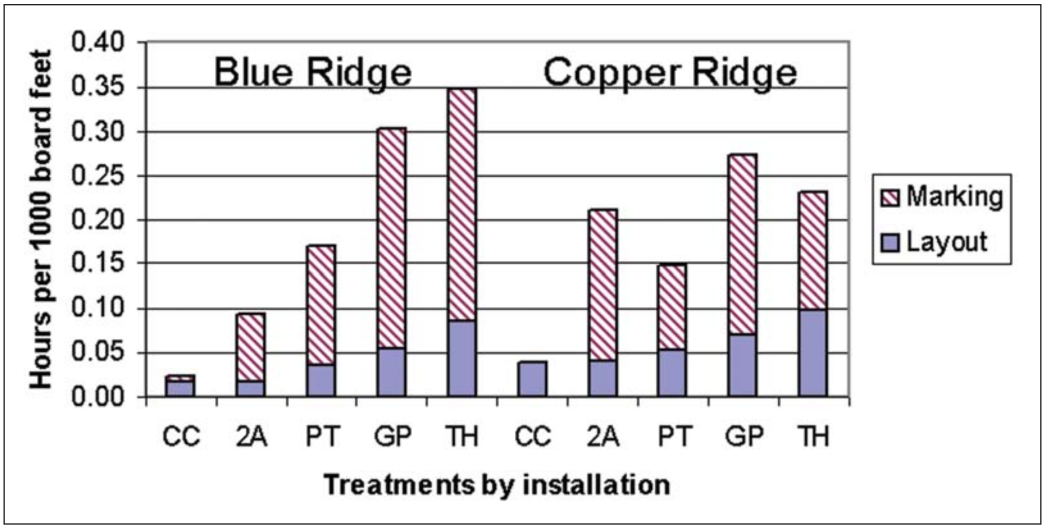

Figure 2—Sale layout and marking costs in hours per thousand board feet (Scribner), by treatment regime (CC = clearcut, 2A = two-age, PT = patch cut, GP = group selection and TH = thinning) and activity for Blue Ridge and Copper Ridge.

only be answered over the long term as the stands develop, important information has already been obtained through the efforts of establishing these studies. Briefly presented below are some of these results, updated to include the second study site (Copper Ridge).

The Blue Ridge and Copper Ridge units represent similar stand ages, but differ in three important respects. First, loggers under contract by the DNR harvested the Blue Ridge unit, and specific log sorts were sold to different buyers. At Copper Ridge, the unit was sold on a lump sum bid basis to a buyer who arranged for logging; this is the usual timber sale process for the DNR. The second difference was that Blue Ridge was harvested by using ground based skidding whereas the steeper terrain of Copper Ridge required a cable harvesting system. Third, although the sale areas were of similar age and area, the total volume removed at Copper Ridge was only about 55 percent of Blue Ridge, reflecting a lower site, smaller trees, more root rot, damage from a 1996 ice storm, and recent thinning sales within in the Copper Ridge area.

Sale Layout Costs

Each replication represented an operational timber sale that required all of the typical activities carried out by DNR foresters including, marking and surveying boundaries, marking cut or leave trees, and the administrative paper work. Once harvesting had begun, operations were monitored for compliance with forest practices rules, contracts and the study design. Figure 2 compares the layout and monitoring costs for the Blue Ridge and Copper Ridge units. The layout times were slightly greater for Copper Ridge compared to Blue Ridge (0.06 compared to 0.04 hours per 1000 board feet) and may reflect the lower removal volume and steeper terrain at Copper Ridge. Marking involved either designating trees for retention (two-age) or harvest (patches, group and thinning). With the exception of the two-age treatment, marking times were less at Copper Ridge, possibly reflecting experience gained at Blue Ridge and the lower volumes. The greater marking times in the two-age treatment at Copper Ridge may reflect the steep terrain. Although the compliance monitoring costs are not well related to the treatment unit, the Copper Ridge unit had slightly greater total times (0.08 compared to 0.06 hours per 1000 board feet).

Harvesting Costs

Stump-to-roadside harvesting costs were collected by Coulter (1999) and Hartley (2003) at Blue Ridge and Copper Ridge respectively. These costs, normalized for piece size and yarding distances, are shown in figure 3 (costs for harvesting the thinning treatment were not collected at Copper Ridge). As expected, costs were lowest for the clearcut units, and the costs were greater (about 1.5 times) for the cable system used at Copper Ridge. For both sites, the costs of harvesting the two-age, patch cut and group selection units were about 1.2 times greater than the clearcut. In addition to harvesting production and costs, soil disturbance, as a result of harvesting, has been measured at Blue Ridge and Copper Ridge. Cable-based harvesting resulted in about 8 percent more area in an undisturbed state compared to ground-based harvesting (Klepac and Reutebuch 2003).

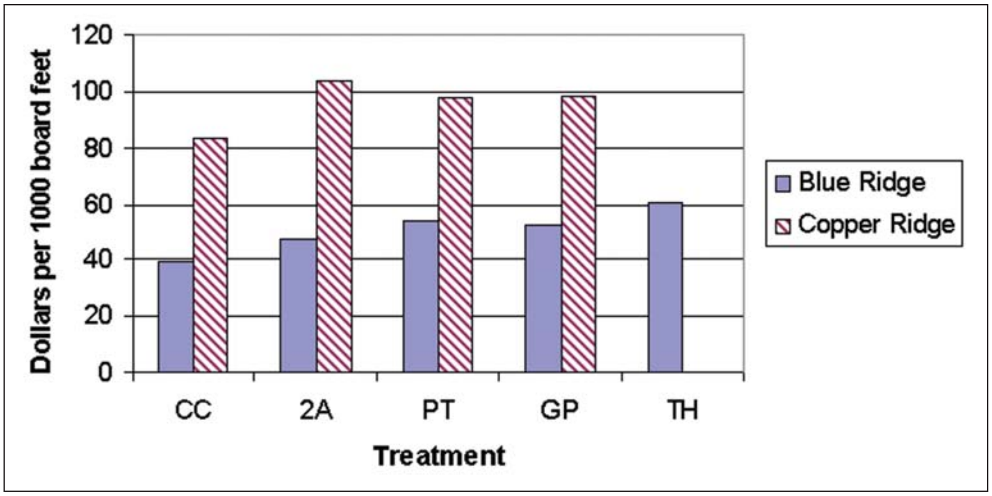

Figure 3—Normalized harvest costs in dollars per thousand board feet (Scribner), by treatment regime (CC = clearcut, 2A = two-age, PT = patch cut, GP = group selection and TH = thinning) for Blue Ridge and Copper Ridge (data for the thinning treatment was not available at Copper Ridge).

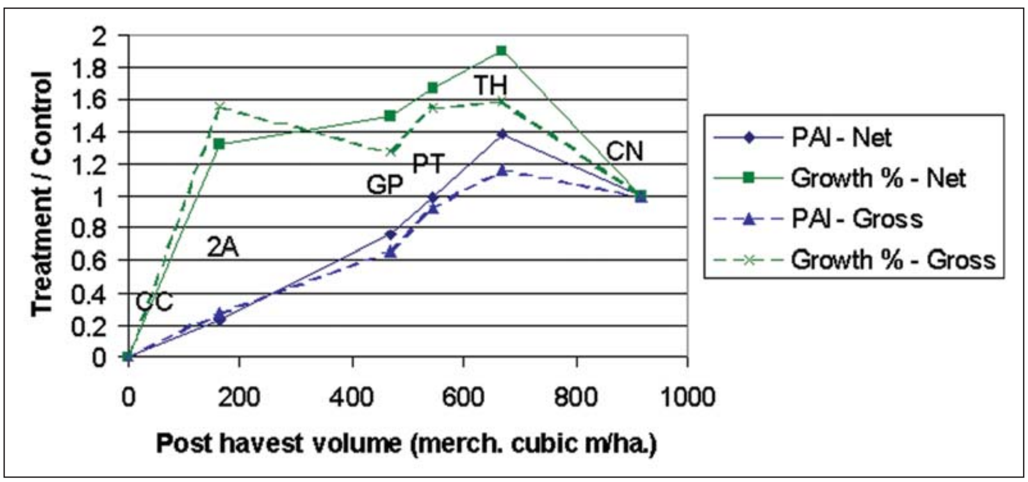

Figure 4—Relative 5-year merchantable cubic volume per hectare periodic annual increment (PAI) and percentage of growth by the post-harvest volume and treatment regime for Blue Ridge (1998-2004) as compared to the unharvested control. Gross volume estimates contain periodic mortality and estimated losses to wind throw (CC = clear-cut, 2A = two-age, PT = patch cut, GP = group selection, TH = thinning, and CN = control).

Timber Production

This is a long-term experiment, and data are being collected to quantify stand growth, regeneration, changes in stand structure and species composition, and the required treatment costs. Data from the first remeasurement at Blue Ridge suggest that the 5-year post-harvest stand volume growth is related to the growing stock (volume) retained after harvest and that thinning appeared to be beneficial in maintaining and enhancing growth of the residual stand (fig. 4). After accounting for mortality (gross growth), the volume growth percent (volume growth as a percent of the initial volume) was similar between the treatments. Periodic volume growth for the control treatment may have been somewhat reduced compared to the other treatments because it has a higher proportion of western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and western redcedar (*Thuja plicata* Donn.). In addition, the control treatment was more noticeably impacted by mortality from root rot and wind throw had the greatest impact on the patch cut (see Curtis et al. 2004). Data from several more measurement cycles on all three replications will be required to determine whether significant differences in post-harvest growth exist between treatments.

Table 2—Bird abundance (mean number of birds detected per point per day), richness (mean number of species detected per point per day) and total species detected, by treatment regime for Blue Ridge and Copper Ridge

	Relative abundance (mean birds/point/visit)		Species richness (mean species/point/visit)		Total species detected	
Treatment	Blue Ridge	Copper Ridge	Blue Ridge	Copper Ridge	Blue Ridge	Copper Ridge
Clearcut	1.37	1.67	0.72	0.67	13	6
Two-age	1.87	4.67	0.66	1.33	15	16
Patch cut	1.81	4.73	0.62	1.33	23	19
Group selection	2.23	4.27	0.93	1.27	18	19
Thinning	2.68	na	0.99	na	26	na
Control	2.97	4.56	1.20	0.90	17	10

Na = not surveyed

Other Values

There are many possible nontimber values that could be studied. With the resources available to date, efforts have focused on two—public reaction to visual impacts and bird use. Bradley et al. (2004) have summarized the results of surveys to assess foreground views at Blue Ridge after treatment. They found that people tended not to discriminate among treatment types but rather by the overall patterns of openings, tree size variation and the amount of green foliage. Later surveys are assessing changes in viewer perceptions with time since harvesting and differences in background scenes created by the range of treatments. Spring bird surveys were done after harvest at Blue Ridge (Wilson et al. 2004) and Copper Ridge by using fixed radius point counts and similar procedures (although Copper Ridge was less intensively sampled with fewer visits and points and did not include the thinning treatment due to cost). In both surveys, the clearcut had the fewest species detected and the lowest relative abundance (number of birds detected per visit per point), although in both cases there were some species only detected in the clearcut (table 2). For Blue Ridge, the relative abundance generally increased with tree cover whereas at Copper Ridge, all of the treatments other than the clearcut were similar. Total number of species detected was greatest in the patch cut units and control at Blue Ridge and in the patch cut and group selection units at Copper Ridge (the thinning treatment was not surveyed).

CONCLUSIONS

The Silvicultural Options for Young-Growth Douglas-fir Forests study was initiated in response to the need for quantitative data on the stand-level responses to alternative silvicultural systems applied to Douglas-fir. Its large-scale, long-term, operational orientation and integrated approach will allow scientists and managers to gain valuable experience in implementing new treatments and generate data to make more informed choices in applying silvicultural treatments.

Key to the success of a project of this scale is the cooperation between the research organization, the landowner, and the operational foresters who are responsible for implementing the treatments. The partnership between PNW scientists, DNR managers and university scientists has provided joint ownership of this project and relevance to the DNR's management objectives.

This study has already generated interest throughout the region. The PNW and DNR have hosted numerous tours of foresters and other interested parties. The British Columbia Ministry of Forests also installed a study based on the same design on Vancouver Island in 2001 and is currently installing another as part of their Silviculture Treatments for Ecosystem Management in the Sayward (STEMS) study (described in this volume, e.g., deMontigny).

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Maintaining Old-Growth Features in Forests Used for Wood Production in Southeast Alaska

Michael H. McClellan[1] and Paul E. Hennon[2]

ABSTRACT

Clearcutting and even-aged management dominated the management of wood-producing forest land in southeast Alaska from the 1950s through the 1990s. Although well suited for wood production, from 1970 to the 1990s, this system came under increasing criticism for its effects on other forest values. To provide a range of scientifically tested silvicultural options, the USDA Forest Service Alaska Region and Pacific Northwest Research Station created a collaborative study of alternatives to clearcutting. The research included retrospective studies to provide early results and interim guidelines to managers and a long-term experimental study to provide greater scientific credibility and wider scope of inference. The experimental study has three blocks with nine operational-scale treatments each. The treatments include both even-age and uneven-age silvicultural systems and vary three factors: cutting intensity, spatial arrangement of retained trees, and patch size. Retrospective study results suggested that partial cutting can maintain diverse and abundant understory plant communities without reductions in stand value owing to species conversions, declining productivity, or increased levels of tree damage. Early results from the experimental study demonstrated the importance of the spatial pattern of retained trees. Tree injuries and mortality increased in treatments that included uniform individual-tree selection. Gap and aggregate treatments were far more effective at protecting retained live trees and snags.

KEYWORDS: Silviculture, variable-retention harvesting, alternatives to clearcutting, old-growth forest, southeast Alaska.

INTRODUCTION

The coastal rainforest of Alaska begins in southern southeast Alaska, extends through Prince William Sound and the Kenai Peninsula, and reaches its limit at Kodiak Island. Temperate conditions and infrequent large-scale disturbance have produced extensive tracts of old-growth forest—roughly 80 percent of the productive forest in southeast Alaska is considered old growth. Western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) dominates these forests (83 percent by number of trees per unit area) and common associates are Sitka spruce (*Picea sitchensis* (Bong.) Carr.), western redcedar (*Thuja plicata* Donn), yellow-cedar (*Chamaecyparis nootkatensis* (D. Don) Spach), and mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.). Most of the forest land in this region resides in the Nation's two largest national forests: the 7.0 million-ha Tongass and the 2.8 million-ha Chugach.

Most of the large-scale timber harvesting in this region was in the productive old-growth forests of southeast Alaska, on the Tongass. Post-war efforts to diversify the economy and provide year-round jobs led in 1954 to the construction of a pulp mill in Ketchikan and, later, a second pulp mill in Sitka. Fifty-year contracts were established to provide national forest timber to these mills and the conversion of uneven-aged old-growth forests to even-aged stands began in earnest (Rakestraw 1981). The dominant silvicultural system from the mid-1950s to the mid- 1990s was a regeneration harvest with clearcutting, followed by natural regeneration without site preparation. On productive sites, managers prescribed precommercial thinning at

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15 to 25 years and commercial thinning at 70 to 80 years. At the end of the 90- to 120-year rotation, the stands were to be clearcut again. By 2001, 267 400 ha in southeast Alaska had been harvested: 175 400 ha on the Tongass, 79 600 ha on Alaska Native corporation lands, and 12 400 ha on State of Alaska and other lands (Barbour et al., in press).

This system efficiently produced wood, but after 1970 it came under increasing criticism for its effects on other forest values: reduced visual quality and associated effects on tourism, degradation of fish and wildlife habitat, reduced slope stability, and simplification of forest structure and associated losses of ecological functions and biological diversity. Uneven-aged management and variable-retention harvest systems were obvious alternatives to the *status quo*, but managers resisted adopting these methods, citing the potential for (1) increased logging costs; (2) increased damage to residual stands from hemlock dwarf mistletoe, windthrow, tree injuries and subsequent wood decay; (3) reduced growth of young trees due to shading by residual trees; and (4) favoring the more shade-tolerant (and less valuable) western hemlock over Sitka spruce.

The adoption of ecosystem management by the Forest Service in the early 1990s increased pressure to consider alternatives to clearcutting, but there was little information from practical experience or scientific study to guide management. Assessing the tradeoffs between maintaining the *status quo* and adopting silvicultural alternatives was impossible without further information, so the Alaska Region and Pacific Northwest Research Station created a collaborative study of alternatives to clearcutting.

STUDY DEVELOPMENT AND IMPLEMENTATION

Much of the debate over old-growth management centers on this question: Can the ecological functions of old-growth be maintained without resorting to a "hands-off" approach, or is active management incompatible with old-growth functions and values? More specifically, can old-growth forests used for wood production provide key old-growth features and functions required by important species? The study *Alternatives to Clearcutting in the Old-Growth Forests of Southeast Alaska* (ATC) (McClellan et al. 2000) was developed to begin to address these broad questions. From the onset, the ATC study involved close collaboration between Forest Service research and management in establishing research objectives, identifying potential sites, designing treatments, and preparing silvicultural prescriptions and marking guides. Tongass National Forest personnel took the lead in preparing the environmental analyses, and preparing and administrating timber sales. Researchers took the lead in collecting, analyzing, and reporting data.

To maintain support for the ATC study, we planned to provide both short-term and long-term results. We would use retrospective studies to provide early results and interim guidelines to managers and concurrently establish an experimental study to provide greater scientific credibility and scope of inference. Research and management jointly established research objectives for the studies and selected the main biological, physical, and socioeconomic responses to study. Biological responses included stand dynamics, understory diversity and abundance, tree damage agent dynamics, bird diversity and abundance, headwater stream productivity, and deer habitat quality. Physical responses included slope stability, groundwater response, and sediment production and transport. Socioeconomic responses included logging feasibility, implementation issues, the costs of planning, implementation, and monitoring, aesthetic qualities, and social acceptability.

Retrospective study fieldwork was completed during 1995 and 1996, when 18 partially cut stands ranging in age from 12 to 96 years were intensively examined. All the stands were at low elevations (< 100 m) and within 2 km of saltwater. The "treatments" were harvest intensity and time since harvest. A subset of the responses listed above were assessed: stand dynamics (growth, regeneration, and mortality) (Deal and Tappeiner 2002), understory abundance and diversity (Deal 2001), tree damage agents (Hennon et al. 2002), and bird diversity, abundance, and reproductive success (De Santo et al. 2003).

Planning of the experimental study began in 1994. Two hypotheses or assumptions guided the treatment design of the experimental study:

1. Forest organisms are well-adapted to natural patterns of disturbance and to the stand structural characteristics created following disturbance.
2. Silvicultural systems that retain key old-growth structural features in sufficient quantity will preserve functions and values associated with old-growth.

What are the "key old-growth structural features" in southeast Alaska? According to a regional working group (Capp et al. 1992), they include large, old, decadent trees, multiple canopy layers, standing snags, down woody debris, and a diverse and abundant herb layer. The treatments were meant to maintain old-growth structure and function, not restore it. Three factors were included in the treatments:

(1) cutting intensity (0 to 100 percentage of basal area retained), (2) spatial arrangement of retained trees (in clumps, gaps, or uniformly distributed), and (3) patch size (32-, 64-, or 96-m diameter clumps or gaps).

The study planners insisted on several important conditions for the experiment: treatments must be assigned through a random process, experimental units must be large enough to encompass much of the natural heterogeneity of the stands and to minimize edge effects, and the study must be replicated widely throughout southeast Alaska. The implementation of the study was at the mercy of wood markets and activist litigation. Recognizing this, many of the cooperating scientists collected extensive pretreatment information that would not only document baseline conditions, but also add to our understanding of unmanaged old-growth forests. Thus, some scientific value could be derived in the event the treatments were not completed.

Nine treatments (fig. 1) were randomly assigned to 18-ha (minimum area) experimental units, replicated in three blocks. Detailed descriptions of the treatments, silvicultural systems and prescriptions, and site characteristics are presented by McClellan et al. (2000) and McClellan (2004). A detailed, reconciled study plan was published to document the study's objectives and methods for future researchers (McClellan et al. 2000).

The experimental treatments were designed to ensure that key old-growth features remained following timber harvesting, but designating live trees and snags for retention does not guarantee they will survive logging operations or subsequent exposure to natural damaging agents such as wind, ice, pests, and pathogens. Live leave trees may be damaged or killed during logging when they are struck by cut trees. Snags are subject to this as well and, in addition, snags are frequently felled to comply with worker safety rules. To determine the ability of each treatment to maintain these structural features, we assessed the fate and condition of retained live trees and large, relatively sound snags (d.b.h. 25 cm or greater and decay class of 1 or 2) immediately following logging and 5 years later.

Examining the timeline of the ATC experimental study might prove instructive to researchers considering undertaking a similar study:

- 1993: U.S. Forest Service Ecosystem Management Research Initiative announced
- 1994: Funding obtained, study planning, first block selected
- 1995: Block 1 (Hanus Bay) established, retrospective study fieldwork began

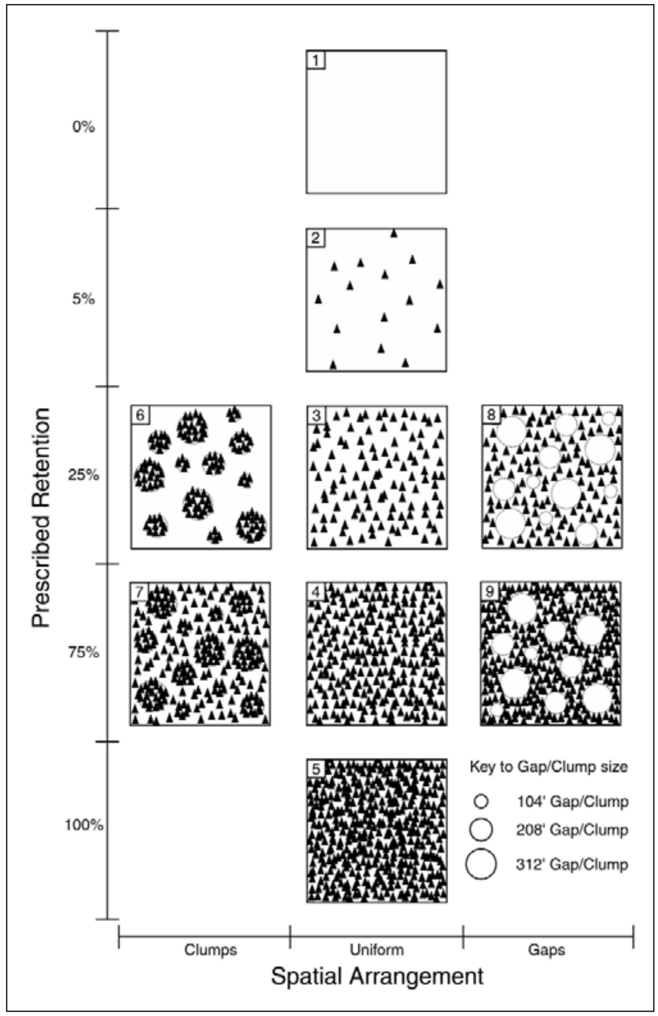

Figure 1—Schematic representation of treatments that are alternatives to clearcuts.

- 1996: Block 2 (Portage Bay) established, retrospective study fieldwork completed, timber sale for Block 1 in litigation
- 1997: Block 3 (Lancaster Cove) established, Block 1 harvested
- 1999: Block 2 (Portage Bay) harvested
- 2002: Fifth-year remeasurement of Block 1, timber sale for Block 3 mired in bankruptcy proceedings
- 2003: All nonvegetation studies terminated
- 2004: Fifth-year remeasurement of Block 2, timber sale for Block 3 reactivated
- 2005: Block 3 harvested.

This illustrates some of the risks of operational-scale, long-term studies. Forces outside the control of researchers can have a profound impact on the conduct of research and may greatly complicate data analysis and reporting of results. Further, the commitment of institutions and cooperating researchers may wane as personnel, funding, and priorities change.

SELECTED RESULTS

The retrospective study achieved the objective of providing early results and interim guidance for managers. The scope of inference for the results is somewhat limited because most of the study sites were in beach-fringe stands, but the results were useful nonetheless. There were three major findings:

1. Partial cutting had no significant effect on tree species composition, and the researchers concluded that concerns regarding shifting species composition, reduced Sitka spruce regeneration, and reduced stand growth were unsubstantiated (Deal and Tappeiner 2002).
2. Partial cutting did not result in significant changes in the amount of windthrow, hemlock dwarf mistletoe infection, bole wounding, or tree mortality (Deal et al. 2002).
3. Overall, the partially cut and uncut areas had similar plant community structures (species composition and abundance) and species richness, but plant community structure differed significantly where >50 percent of the basal area had been removed (Deal 2001). Deal (2001) suggested that similarities between old-growth stand structure and the heterogeneous stand structures of partially cut stands could account for the observed similarities in understory plant communities.

These results were reported in the traditional scientific literature, but the researchers used several other methods to ensure the information got to managers quickly, including annual progress reports, briefings at regional resource-specialist meetings, and field tours.

Early results from the experimental study have included insights gained from pretreatment measurements in the 27 unmanaged old-growth stands, coupled with early post-treatment response data. These include findings on disturbance dynamics and old-growth forest structure (Hennon and McClellan 1999, 2003), social acceptability of alternatives to clearcutting (Burchfield et al. 2003, Clausen and Schroeder 2004), avian ecology (De Santo and Willson 2001, De Santo et al. 2003), groundwater response (Johnson et al., n.d.), and headwater stream trophic relationships (Musslewhite and Wipfli 2004; Wipfli and Gregovich 2002; Wipfli, in press). As with the retrospective study, researchers have used briefings, field visits, and internal reports to convey their findings to managers, in addition to scientific publications. The experimental sites are particularly important as demonstration sites, and there have been many visits by researchers, managers, news media, and policy makers.

Snag survival immediately following logging (table 1) demonstrated that treatments where 25 percent or less of the basal area was retained generally did not preserve enough snags to meet the requirements of the Alaska Region old-growth definitions (Capp et al. 1992). As expected, retaining trees and snags in clumps generally protected a higher percentage of snags for a given level of basal-area retention. At each site, only three of seven noncontrol treatments protected sufficient numbers of snags. The results from the Portage Bay unit with 75-percent retention and individual-tree selection are interesting: even though 75 percent of the existing snags were retained, there were too few to meet the minimum requirements of the old-growth definition. This suggests that in old-growth stands with fewer snags than normal, extra effort may be necessary to retain the desired number of residual snags.

The rates of top, bole, and root wounding in live trees after logging also demonstrated the importance of the spatial distribution of retained trees. Overall, 18 percent of the retained trees at Hanus Bay (n = 1639) sustained some form of injury and at Portage Bay 29 percent of the trees (n = 2950) were injured. Injury rates varied widely by treatment (fig. 2): treatments including individual-tree selection promoted high injury rates to leave trees in contrast to treatments where cutting was concentrated in clumps (gaps) and injury rates were much lower.

Analysis is ongoing of fifth-year response data from the first two blocks. We expect that this will soon provide useful findings on leave-tree growth and mortality, incidence of windthrow and other damaging agents, conifer regeneration, understory diversity and abundance, and deer-forage availability.

RELEVANCE AND IMPACT

Researchers are engaged in a lively debate over the role of large-scale, long-term studies in providing the basis for science-based resource management. The studies consume significant resources, and there is the ever-present risk that they will become irrelevant as societal demands and expectations evolve over the life of the study. The ATC study is now 10 years old, and the third block has not been harvested; it is worth asking whether the study remains useful and relevant. Despite great controversy, old-growth harvesting

Table 1—Post-harvest survival of class 1 and 2 snags with d.b.h. 25 cm or greater. Bold text indicates that after treatment the stand included enough snags to meet the criteria of the Alaska Region old-growth definition for this forest type (Capp et al. 1992).

	Treatment number[a]								
	1	2	8	3	6	9	4	7	5
	Treatment description								
	Clearcut	Wildlife Tree	ITS[b]/Gaps	ITS	Clump	Gaps	ITS	ITS/Clump	Control
	Percentage of basal-area retention								
Site	0	5	25	25	25	75	75	75	100
Hanus Bay	8.8	0.0	18.8	16.7	64.3	**72.4**	**90.5**	**83.3**	**100**
Portage Bay	4.4	10.7	5.9	13.3	**47.8**	**52.9**	75.0	**100.0**	**100**

[a] Treatment number from figure 1

[b] ITS = uniform individual-tree selection From McClellan (2004).

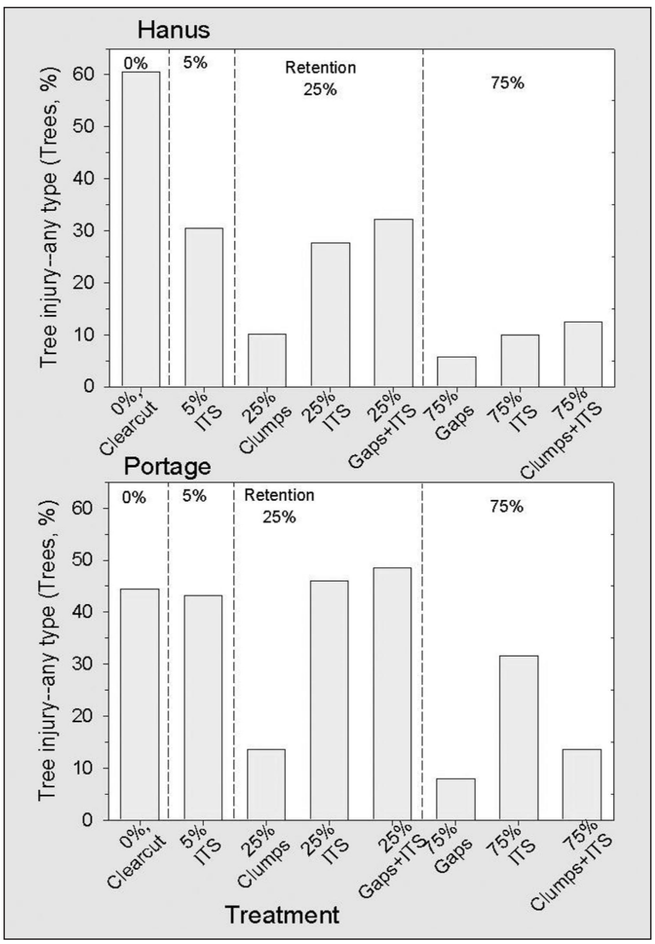

Figure 2—The percentage of residual trees wounded during logging, by treatment.

continues on national forest, state, and Alaska Native corporation lands in southeast Alaska. For the most part, young-growth stands in this region are still too young to be harvested economically. Some opportunities exist for commercial thinning of young-growth, but the timber industry in southeast Alaska is largely dependent on old-growth harvesting and will continue to be for the next decade or longer. Much of this harvesting will employ variable-retention, so it is necessary to continue research to quantify the tradeoffs associated with its use. Managers of the Tongass National Forest view the ATC study as a continuing source of scientific information to guide management and as an essential monitoring tool to determine the effects of clearcutting alternatives. In addition, the costs and benefits of variable-retention harvesting in old-growth forests continue to be debated among resource managers, the timber industry, and interested citizens—raising issues that cannot be resolved in the absence of credible scientific information.

Finally, we must ask if the ATC study has affected management, at least on national forest land. There have been dramatic changes in timber-harvesting practices since the onset of the study in 1994. In that year, 3683 ha were harvested, all by clearcutting. The revised Tongass land management record of decision (USDA FS 1997: 5) estimated that 80 percent of the planned regeneration harvesting would be clearcutting with subsequent even-aged management. At least 20 percent would be variable-retention harvesting with two-aged management. The record of decision further predicted that about 80 percent of the allowable harvest would employ conventional logging systems and the remaining 20 percent would come from lands that were isolated or that required special yarding equipment, such as helicopters (USDA FS 1997: 8). By 2002, however, a review of silvicultural prescriptions in Tongass National Forest project-planning documents revealed that 29 percent prescribed even-aged management, 33 percent prescribed two-aged management, and 38 percent prescribed uneven-aged management. The prescribed logging systems were 37 percent conventional and 63 percent helicopter.[3] This rapid shift in management practices cannot be attributed solely to the impact of the ATC study, but discussions with managers reveal it clearly played a role. The findings of the retrospective study and the early results from the experimental study allayed some of the concerns over variable-retention harvesting. The experimental study was conducted at an operational scale and relied on standard timber sales to implement the treatments, effectively demonstrating that variable-retention harvesting was technically feasible and viable in the existing timber marketplace. If the experiments were smaller scale (as were many silvicultural field trials in the past) or implemented with service contracts, it is likely the influence on managers would have been much less.

ACKNOWLEDGMENTS

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Montane Alternative Silvicultural Systems (MASS): Designing Experiments for the Future

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Local and global demand to sustain multiple values from forest land has created pressure to diversify silvicultural systems. In response, the Montane Alternative Silvicultural Systems (MASS) project was established in 1993 to test silvicultural alternatives to clearcutting that retain elements of preharvest forest structure. Objectives are to document the operational costs and feasibility and to study the biological and silvicultural impacts. To date, there have been more than 20 integrated research studies conducted at the site addressing feasibility and economics, soil disturbance and productivity, decomposition, leaching and nutrition, microclimate, ecophysiology of conifers, natural and planted regeneration, seedling response to competition and nutrition, vegetation succession and forest structure, growth and yield, forest bird and canopy insect diversity, forest health, and the genetic consequences of alternative silvicultural systems. The project is a factorial design with three replicates of four silvicultural treatments: clearcut, patch cut, green-tree retention, and shelterwood. Although the MASS project was established prior to the development and implementation of retention silvicultural systems in coastal British Columbia, it provides a test bed for scientific experiments that address questions about the ecological impacts of aggregated and dispersed retention systems. Results from established studies and plans for future work aimed at moving toward science-based forest management are discussed.

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Comparing Changes in Scenic Beauty Produced by Green-Tree Retention Harvests, Thinnings and Clearcuts: Evidence From Three Pacific Northwest Experiments

Robert G. Ribe[1]

ABSTRACT

The same in-stand photographs were taken before and after six different green-tree retention harvests, including one in old growth. More such photo replicate pairs were also taken in light and heavy thinnings of young stand and in clearcuts. All the photos were rated for scenic beauty by samples of the public. Short-term changes in scenic beauty attributable to the forest treatments were computed from these ratings. High visual impacts meeting very low scenic integrity standards were observed for clearcuts, 15-percent aggregated-retention harvests of mature forests, and 15-percent mixed-pattern retention harvests of old growth. Moderate impacts meeting low scenic integrity standards were observed in 40-percent aggregated- and 15-percent dispersed-retention harvests of mature forests. Both thinnings produced low impacts meeting moderate scenic integrity standards. Treatments of 40-percent dispersed and 75-percent aggregated retention produced low impacts that can meet high scenic integrity standards. Some green-tree retention harvests have clear value in meeting aesthetic goals in forest management.

KEYWORDS: Scenic beauty, timber harvests, public perceptions, green-tree retention.

INTRODUCTION

Visual aesthetics are often critical factors affecting forest management decisions. Increasing the beauty of managed forests can enhance the social acceptability of forest management (Ribe 2002) and is often required in popular views, recreation areas, frequently seen places, and other areas strongly valued by the public (USDA FS 1995). Forest aesthetic choices often are evaluated through environmental impact statements. Aesthetic impacts must be included in these, and the standard for all assessments is change from baseline environmental conditions (Jain et al. 1993).

Many studies of aesthetic perceptions of forestry have been conducted (Ribe 1989), but few have investigated changes in the same forests or scenes due to forest treatments, as would best inform impact assessments. Instead, studies typically compare different forests and sometimes derive scenic beauty prediction models from which the visual impact of forest changes might be computed or inferred.

The state of the art in scenic impact assessment emphasizes evaluation of scenic change over time against visual standards that describe acceptable amounts of change in different places. The standards used by the USDA Forest Service consist of five “scenic integrity levels” ranging from “very low” to “very high,” with higher levels typically applied to more scenic, seen or valued landscapes (USDA FS 1995). Scientific evidence is needed to inform these assessments.

Study Objectives

This study investigated visual-aesthetic change inside forests as a result of harvests and thinnings in western Oregon and Washington. It investigated the worst-case, short-term impacts of recently conducted harvests. These impacts often need the most attention in improving social

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perceptions of forestry (Sheppard 2001). An investigation of green-tree retention harvests was emphasized because these are gaining attention (Franklin et al. 1997) and need to be compared to more traditional and sometimes aesthetically controversial harvests. Changes in scenic beauty because of clearcuts, thinned forests, and an old-growth harvest were, therefore, compared to green-tree retention harvests.

Numerous photo points were established inside experimental forests throughout western Washington and Oregon. The same scene was photographed from all of these points before and after the various harvests. A sample of these pairs of replicated photos were rated for scenic beauty by public respondents. Estimates of changes in average perceived scenic beauty ratings were found. These were compared to assess which treatments tend to produce which visual impact levels. The same changes in beauty were also compared against acceptable changes indicated by visual integrity standards used by the Forest Service in landscape planning (USDA FS 1995).

Background

Green-tree retention harvests are proposed by "New Forestry" (Franklin 1989) as alternatives to clearcutting. The goals of such alternatives are generally perceived more positively than conventional forestry by placing more emphasis on sustaining ecological health (Ribe and Matteson 2002). When viewed from inside the forest, green-tree retention harvests have aesthetic potential (Brunson and Shelby 1992), but not all aspects of such ecologically-derived harvest prescriptions will be necessarily aesthetically successful (Gobster 1996). Much may depend on how they manifest the "violence" of harvesting (Benson and Ullrich 1981). Scenic impacts, as a result of various forest harvests, should be compared to an old-growth harvest. Harvesting old growth forests is controversial in the Pacific Northwest, in part because of the loss of aesthetic values (Brunson and Shelby 1992).

To the extent that green-tree retention harvests leave more standing trees than most traditional harvests, they should be more aesthetically successful (Buhyoff et al. 1986, Schroeder and Daniel 1981, Vodak et al. 1985), although too few trees can be left standing (Daniel and Boster 1976, Schweitzer et al. 1976). Retaining more large green trees should aid aesthetic value (Brown and Daniel 1986, Daniel and Boster 1976, Schroeder and Daniel 1981).

Forest thinnings tend to be aesthetically preferred to other forest harvests, provided that down wood is removed (Kenner and McCool 1985), not too many trees are removed (Vodak et al. 1985), and larger trees are retained (Buhyoff et al. 1986). Thinned forests, after they regain ground vegetation, can be preferred to unmanaged forests of the same age (Bradley et al. 2004, Brush 1979).

METHODS

Study photographs came from the Demonstration of Ecosystem Management Options (DEMO) study (Aubry et al. 1999), the Long-Term Ecosystem Productivity (LTEP) study (Homann et al. 2001), and the Young Stands Study (YSS) (Hunter 2001, Kellog et al. 1998). These studies are all forest harvest experiments conducted in conifer-dominated forests in western Washington and Oregon. All are randomized block designs with harvest treatments replicated at locations exhibiting various altitudes and forest conditions.

The nine forest treatments investigated here were drawn from the three studies listed above. These are listed across the bottom of figure 1 and were implemented in forests outlined below.

The DEMO study provided examples of 15-, 40- and 75-percent retention harvests. The DEMO harvest sites were reasonably representative of mature, coniferous forests on public lands in western Washington and Oregon. The forests at the six DEMO blocks were between 65- and 170-years old and dominated by Douglas-fir (*Pseudotsuga menziessi* (Mirb.) Franco). The DEMO blocks included one on a level site, one on moderate slopes of 9 to 33 degrees, two mostly on moderately steep slopes of 40 to 53 degrees, and two mostly on steep slopes of 50 to 66 degrees. These slopes were relatively even within most of the units at all blocks. Four blocks contained pretreatment stands with densities mainly in the 200 to 500 trees/ha range, and the other two had mainly 700 to 1300 trees/ha. The basal area of the DEMO forests fell mostly in the 40 to 90 m^2/ha range with the mature cohort of trees typically at 38 to 76 cm, 1.37 m above ground (d.b.h.). One block had little ground vegetation and understory with extensive visual penetration. The other five pretreatment forests had ample ground vegetation and were typically heterogeneous enough to include areas of understory and limited visual penetration. (See Aubry et al. (1999) and other articles in this report for greater detail about the DEMO forests.)

The DEMO treatment units were 13 ha and square or slightly rectangular. For the aggregated-retention treatments, the percentage of retention was by area of the unit. For dispersed retention treatments, the percentage of retention was by basal area to match that of the corresponding percentage,

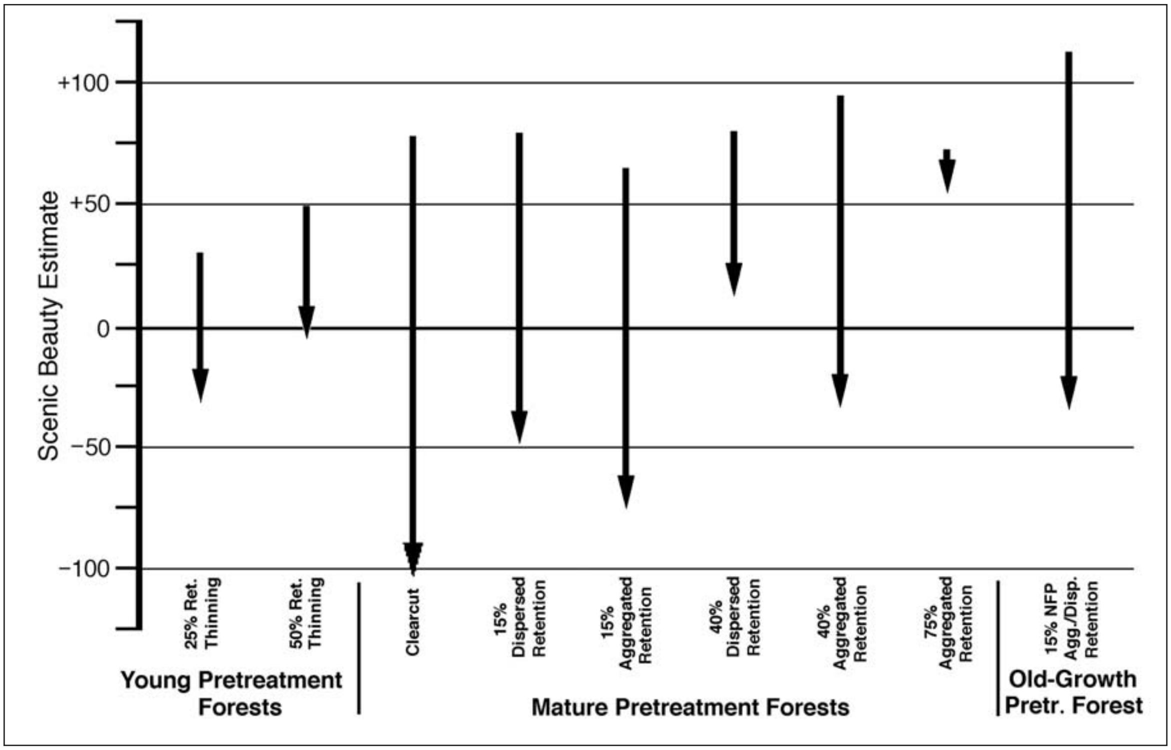

Figure 1—Observed changes in scenic beauty due to forest treatments.

aggregated-retention treatment within the corresponding block. The 15-percent aggregated-retention treatments contained two 1-ha, 56-m diameter, circular aggregates of uncut forest near opposite corners of the unit. The 40-percent aggregated-retention treatments contained five aggregates of the same size and shape, arranged in a dice-shaped pattern (illustrated in other articles in this report). This unnatural geometry of the retention aggregates was for scientific purposes related to other studies. It was not obvious when seen from inside the units and even less detectable in the photographs used for this study.

One LTEP block of four replicates (near Sappho, Washington) provided example clearcuts for comparison to the DEMO and YSS retention harvests. The LTEP block also provided an example of a 40-percent dispersed-retention harvest, by basal area (50 percent by tree density) that was employed in this study. Prior to harvesting, this block contained a 70-year-old, second-growth forest dominated by Douglas-fir on level ground. This block contained pretreatment stands with densities in the 700 to 800 trees/ha range. The basal area of these forests fell mostly in the 55 to 70 m^2/ha range, with the mature cohort of trees typically at 38 to 51 cm d.b.h. The clearcuts units in the LTEP study were 6 ha and square or slightly rectangular.

Four YSS blocks in the Willamette National Forest of Oregon provided examples of thinned young forests. Each of these included a light thin retaining a dispersed pattern of 50 percent stems, and a heavy thin retaining 25 percent dispersed stems. Hardwoods were retained as much as possible. Prior to thinning, these blocks contained 30- to 50-year-old, even-aged forests dominated by Douglas-fir. The YSS blocks included one on a level site and three on moderate slopes of 9 to 24 degrees. These YSS blocks contained pretreatment stands with densities in the 500 to 800 trees/ha range. The basal area of these pretreatment forests fell mostly in the 20 to 25 m^2/ha range, with the trees typically at 25 to 31 cm d.b.h. The YSS thinning units varied from 14 to 53 ha and occurred at altitudes from 134 to 276 m.

An old-growth harvest was included in the study for comparison. This entailed photo sampling from two different sites. Pretreatment photographs (n=48) came from old-growth forests on the Umpqua National Forest of Oregon that were sampled for the DEMO study but not harvested. Corresponding post-treatment photographs came from a recent old-growth harvest in the same national forest, as described later. This old-growth harvest followed Northwest Forest Plan standards (USDA and USDI 1994). It contained 15-percent density retention roughly split between aggregates and dispersed trees elsewhere in the unit. Down wood was mostly removed except for scattered, large logs.

Field Photography

Permanent monuments were driven into the ground within every treatment unit in all three studies. These were laid out in grids in the DEMO and LTEP units, and along transects in the YSS units. In all cases, the array of monuments was small and roughly centered within each unit so that photographs from monuments mainly captured the corresponding treatments. Predetermined subsets of monuments served as photographic sampling points, with care taken to ensure unbiased representation of the scenery. These points were located by protocols determined prior to field inspection of the forests or knowledge of how the monuments would fall within the forest structure and terrain. All photographs were replicated, once before treatment and once within 3 months after treatment.

All photographs were taken from sampling monuments in specified directions using a 35mm SLR conventional camera with a 35mm lens. The horizon, or estimated horizon if invisible, was placed one third of the way up each image, even when photographs were taken up or down slopes. For side slopes, the horizon point at the center of the image followed this rule. If a tree, shrub or rock obstructed a prescribed photo, the photographer moved up to 1 m in the shortest possible direction to minimize the obstruction in the photo. Photos were taken within 3 hours of noon, standard time.

A standard pattern of eight photos was taken in each DEMO unit from monuments along the edges and at the corners of the grid, all aimed at the center of the grid. This yielded 48 photo replicate pairs for each DEMO treatment across the six blocks. This pattern of photos was designed for representative post-treatment sampling of the most scenically-complex, 40-percent aggregated-retention treatment. The pattern of photos was designed by reference to the pattern of future felling for that treatment that was fixed in advance in relation to the grid of monuments. The resulting set of post-treatment scenes captured a variety of views, i.e., views inside uncut aggregates, across larger areas of harvested matrix, looking at unharvested matrix between uncut aggregates, and views of nearby aggregates with harvested matrix in the foreground. This mix of sample photos sought to capture views similar to those encountered on a random hike through this treatment. The other DEMO treatments were homogeneous enough for the same photo pattern to representatively sample scenery there as well.

A standard set of five points within the LTEP units were sampled. Photos were taken from each of these in the four cardinal compass directions. This yielded 20 photos per treatment unit. There were 16 clearcuts in the Sappho LTEP block employed in this study. This yielded 320 photos for clearcuts. There was also one dispersed retention harvest unit in the same block that met the same 40-percent, dispersed-retention basal area as one of the DEMO treatments being studied, yielding 20 more sample photos of that treatment.

Photographs were taken within each YSS unit from four randomly selected monuments. Photos were taken at each in the four cardinal compass directions. This yielded 16 photos per unit, or 64 photos per treatment across the four YSS blocks.

Twelve photographs inside old-growth forests were randomly selected. Copies of these were taken into the Umpqua National Forest old-growth harvest described above. Photos of this old-growth harvest were found and taken to match the untreated old-growth photos as closely as possible with respect to slopes and the position of stumps and standing trees within the photo frames. This method served to produce photos that were plausible as “post-treatment replicates” of the pretreatment old-growth photos. This yielded 12 pairs of replicated photos for this constructed example of an old-growth harvest.

Controlling for Down Wood in Photos

Because down wood left after harvest adversely affects scenic beauty perceptions (Brown and Daniel 1986, Daniel and Boster 1976, Schroeder and Daniel 1981, Schweitzer et al. 1976, Vodak et al. 1985), it needed to be controlled for in photos used in public surveys. To represent down wood similarly within all treatments’ photo samples, half of each treatment's post-treatment photos were sampled to exhibit a high level of down wood. The pairs of replicated photos that included high post-treatment down wood needed to be separated out prior to final sampling for public surveys. This was done according to different rules depending on the study from which the photos came.

High down wood LTEP and YSS post-treatment photos were those taken of units where most harvest residue, including tops, limbs, and many logs remained on site. This was a prescribed, permanent condition in half the LTEP clearcut units photographed (n=160 photos) and the one 40-percent dispersed retention LTEP unit (n=20). In one of the YSS blocks, high down wood photos were taken before harvest residue were cleaned up (n=16 photos in each of the two treatments). In the other three YSS blocks (n=48 photos per treatment), low down wood photos were taken after harvest residue was removed.

High down wood post-treatment photos from the DEMO treatments were identified according to field measurements of the area depicted within the photos. Threshold values of total down wood per hectare were used. These were derived from sample-based estimates of the volume per hectare of course wood, course litter, and snags leaning more than 15º. The course wood (>10 cm diameter) estimates came from the 6-m transect shown in the photo and closest to the photo point. The course litter (5-10 cm diameter) estimates came from six 0.2-ha x 0.5 m microplots along the same transect. The leaning snags estimate came from the 0.08-ha circular plot shown in the photo and closest to the photo point. Leaning, dead trees, not rooted vertical ones, are more likely to adversely affect beauty perceptions (Brunson and Shelby 1992, Brush 1979).

The threshold values were as follows: among photos that depicted a foreground of 15-percent dispersed retention, or of harvested matrix within any aggregated retention treatment, those with more than 300 m^3/ha of down wood were classified as high down wood. For photos that depicted 40-percent dispersed retention harvests, the threshold was 200 m^3/ha. If a photo depicted unharvested aggregate in the foreground, the threshold value was 100 m^3/ha.

Sampling of Photos for Public Surveys

A subsample of the pairs of replicated photos (the same scene taken before and after forest treatments) was selected to represent each such treatment in public surveys. The number of photos sampled needed to reliably represent the scenic variability encountered within forests produced by any one treatment (Palmer and Hoffman 2001). To identify this sample size, public surveys were conducted in stages, each adding more photos until a reliable sample size was found. The first stage included eight pairs of replicated photos from each treatment. Additional stages added four more of these photo pairs from each treatment. The reliability test after each survey stage was the standard error of the mean perceived scenic beauty value (described later) among the post-treatment scenes for every treatment. Only the samples of the post-treatment scene were tested because they had more variability in scenic beauty ratings. These test values estimated the variability expected in mean scenic beauty found among other samples of the same number of scenes that might be sampled for each treatment. Once the test values for all treatments fell below 10 percent of the full range of perceived scenic beauty observed in the study, the photo sample size was deemed reliable. This occurred after two survey stages, at a final sample size of 12 pairs of replicated photos per treatment.

Some photo replicate pairs were eliminated before final subsampling for the public surveys. These were instances where one or both of the photos in each pair had one of four problems: (1) very poor photographic quality; (2) too much plastic flagging in the immediate foreground (placed by field researchers); (3) a close-up obstruction filling more than 25 percent of the photo; or (4) taken close to and toward the edge of a treatment unit, so that the wrong surrounding forest or neighboring treatment was depicted. This screening eliminated 9 percent of DEMO, 16 percent of LTEP, and 11 percent of YSS photo pairs.

For the first stage of public surveying, four pairs of replicated photos showing higher amounts of down wood, and four other photo pairs showing lower amounts of down wood were randomly selected for each treatment, yielding eight total photo pairs per treatment. The same procedure was used for the second stage, except two pairs per down wood level per treatment were selected. This yielded a total final sample of 12 (8+4) photo pairs per treatment.

Public Perception Surveys

All photo replicate pairs for all treatments were placed into a mail or live-group survey instrument. (Two survey protocols were employed due to funding limitations and the need to keep surveys short enough to elicit high response rates.) For the first stage survey, two randomly selected post-treatment photos of each treatment were allocated to the mail survey. This mail survey also included single, randomly-selected, pretreatment photos of a young forest, a mature forest, and an old-growth forest, as well as forestry attitude questions. All remaining first-stage photos were allocated to a survey of live groups described below. Care was taken to insure the comparability of the survey samples, as described later.

The mail survey photographs were printed in color, in random order, eight to a page, in an 28 x 43 cm (11 x 17 in) fan-fold survey. A random sample of 1,669 residents of western Washington and Oregon received letters requesting participation. Of these, 698 volunteered by returning postcards affirmatively as the compliant sample to whom the survey was sent. Two prompting letters were sent at successive twelve day intervals. In all, 647 returned the survey for a 93-percent response rate within the compliant sample, or 39 percent of the original sample.

Respondents were instructed that the photos included examples of forests with and without various timber harvests. They were instructed to rate the scenes for scenic beauty on a numeric scale from -5 to +5, ranging from “very ugly” (-5) to “very beautiful” (+5), with zero value ratings assigned to photos they found neither beautiful nor ugly or were undecided about.

The photos not allocated to the mail survey were projected as slides for rating by groups as an activity during their regular meetings. The groups included service clubs, higher education classes, outdoor interest groups, and business clubs representing economies significantly dependent on timber harvesting. These respondents were given the same instructions, and used the same rating scale. Each respondent rated the slides privately on their own survey. The photos were projected in random orders, and each slide was shown once for 7 seconds.

Six of the photo replicate pairs from each treatment, plus the pretreatment photos not included in the mail survey, were allocated to the first-stage, live-groups survey. Fifteen groups participated in this first stage, providing 271 respondents. Four additional photo replicate pairs from every forest treatment were in the second-stage, live-groups survey. Ten groups participated in this stage, providing 210 respondents. A few of the meeting attendees elected not to participate, and were not tracked, so a response rate can not be reported.

The live group slide rating surveys constituted a less random sample of the public than the mail survey. The most likely difference in rating bias between these two samples came from a significant difference in their representation of forest protection versus forest production attitudes. The ratings of these two categories of respondents was strongly correlated but with significantly different average values due to different aesthetic standards (Ribe 2002).

Accordingly, various live groups were recruited seeking a respondent sample with overall attitudes toward timber harvesting like that from the mail survey. The mail survey was completed first, yielding its distribution of attitude questionnaire responses. Live groups of respondents were recruited to roughly duplicate this distribution of environmental biases, as suggested by their defining mission or common interest. Groups' expected attitudes toward timber harvesting were also anticipated according to their urban versus rural location (Hansis 1995, Tremblay and Dunlap 1978), their members' typical length of residence in the region (Xu and Bengston 1997), and gender balance (Hansis 1995, Levine and Langenau 1979).

Measuring Perceptions

A scenic beauty estimate (SBE) was computed for each scene from all its ratings (Daniel and Boster 1976). This method of averaging ratings removes differences in how respondents distribute their ratings along the scale, and thereby standardizes just their perceptions of relative beauty. In this study, the respondents used a bipolar rating scale, producing SBE values that took on both positive and negative values, scaled to a zero point where the average respondent changed from negative (ugly) to positive (beautiful) ratings (Ribe 1988).

RESULTS

The changes in average SBE values across the photos representing each treatment are graphed in figure 1. All treatments produced reductions in scenic beauty. Consequently, the top of each arrow in figure 1 indicates the average SBE of the pretreatment photos, and the bottom indicates the average of the post-treatment photos. Inspection of the top of the arrows suggests an increasing trend in pretreatment scenic beauty from young to mature to old-growth forests. Within that pattern there was some chance variability in the level of SBEs observed in the pretreatment forests assigned to different treatments.

Inspection of figure 1 indicates several results regarding the position of different treatments' scenic beauty changes within the range of observed SBE levels. The two levels of thinning both produced similar reductions in SBEs such that the difference in their post-treatment SBEs may be accounted for by the chance difference in their pretreatment SBEs. Treatments of mature forests exhibited an increasing trend of post-treatment SBEs with increasing levels of green-tree retention. Within single retention levels (15 or 40 percent), dispersed retention produced higher post-treatment SBEs than aggregated retention. The dispersed 40-percent and aggregated 75-percent retention treatments produced positive post-treatment SBEs, while all the other mature forest treatments produced negative post-treatment SBEs. The 15-percent retention treatment of old-growth produced a change from the highest observed pretreatment SBE to a moderately negative post-treatment SBE.

Inspection of figure 2 indicates results about the comparative magnitude of scenic beauty changes due to the treatments. Figure 2 shows differences in scenic impact ordered by absolute change in average SBEs. All pairs of these SBE changes were tested for statistically significant differences using *t* tests, at $p = 0.05$. The sets of scenic impacts that are not statistically different are indicated by the bars across the top of figure 2. Note that the magnitude

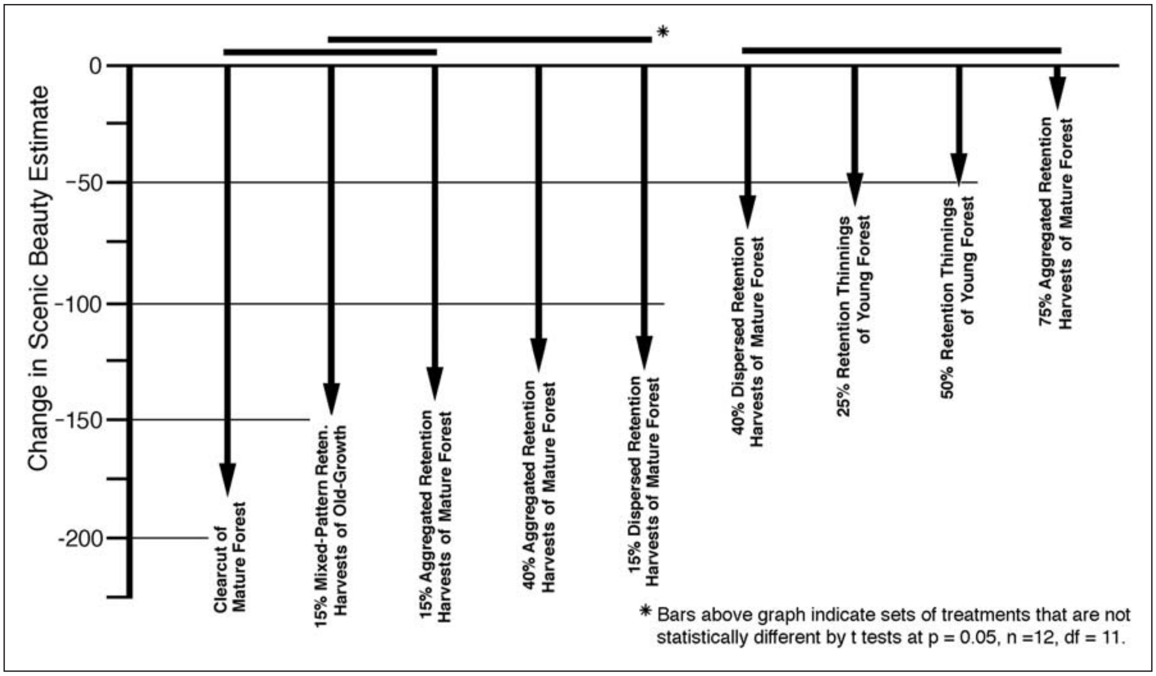

Figure 2—Comparing magnitudes of changes in scenic beauty due to forest treatments.

of average SBE change for the 75-percent aggregated-retention harvest was much smaller than all the other treatments (fig. 2). However, this obscures variation in SBE changes encountered within its various pairs of replicated photos between patches of harvested matrix versus unharvested aggregates. This variation produced a large enough standard deviation in SBE change values to cause it to be statistically the same as the other three treatments at the right of figure 2.

FINDINGS

The three sets of statistically-the-same absolute changes in scenic beauty in figure 2 indicate three short-term, in-stand scenic impact levels. These are generic, evidence-based levels useful for assessing impacts widely, as in forest plans and watershed analyses. At the level of a single harvest, landscape architects may marginally modify these impacts based on the design of each project:

- High impacts = clearcuts.
- High to moderate impacts = old-growth harvests executed under guidelines from the Northwest Forest Plans and 15-percent aggregated-retention harvests in mature forests.
- Moderate impacts = harvests of mature forests that employ 15-percent dispersed retention or 40-percent aggregated retention.
- Low impacts = thinnings and mature-forest harvests employing 40-percent dispersed or 75-percent aggregated retention. The latter can produce very low impacts if the harvested patches are placed out of view.

A comparison of the magnitude and position of scenic changes in figure 1 allows generic comparison to what would be acceptable, low impacts at various visual integrity levels:

- Clearcuts and 15-percent aggregated retention harvests produce very large changes from strongly beautiful to strongly ugly, consistent with low scenic impacts only against the "very low" scenic integrity standard.
- Old-growth harvests executed under the guidelines of the Northwest Forest Plan also fall into this “very low” scenic integrity standard. They produce changes from strongly very beautiful to moderately ugly, a more than moderate change incompatible with preharvest natural landscapes.
- 15-percent dispersed and 40-percent aggregated-retention harvests produce large changes from strongly beautiful to moderately ugly, consistent with low scenic impacts only against the “low” scenic integrity standard.
- Thinned young forests, whether heavy or light, produce short-term changes from moderately beautiful to moderately ugly, consistent with low scenic impacts against

the “moderate” scenic integrity standard. These are slight scenic changes that tend to be visually subordinate to continued, intact forest scenery.

- 40-percent dispersed and 75-percent aggregated-retention harvests produce changes from strongly beautiful to moderately beautiful forest, consistent with low visual impacts against the “high” scenic integrity standard. They maintain the positively beautiful forest landscape.

Further research is needed regarding longer term scenic impacts of these and other alternative timber harvests (Shelby et al. 2003), and how perception of such harvests differs among people with different knowledge of the values and risks each entails (Bradley et al. 2004).

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Ten-Year Results of the Forest Ecosystem Research Program – Successes and Challenges

Mike R. Saunders[1] and Robert G. Wagner[2]

ABSTRACT

The Forest Ecosystem Research Program (FERP) was initiated by the University of Maine in 1993 on the Penobscot Experiment Forest in Bradley, Maine. FERP is comparing three expanding-gap silvicultural treatments designed to emulate the 1-percent natural disturbance frequency common within the Acadian ecoregion: (1) 20-percent canopy removal on a 10-year cutting cycle (creating 0.2-ha openings) with 10 percent of the basal area retained as permanent reserve trees and a 50-year rest period following the first five cycles; (2) 10-percent canopy removal on a 10-year cycle (creating 0.1-ha openings) with 30 percent of the basal area retained as permanent reserve trees and no rest period, and (3) an unharvested control. The treatment plots are roughly 10 ha in size and replicated three times in a randomized complete block design. The study has provided a template for examining a variety of ecological questions related to gap disturbances. Gap harvesting influenced the volume and biomass of downed woody debris (DWD) and increased vegetation abundance and diversity relative to natural gaps and undisturbed canopy. Although avian communities were largely unaffected by gaps, amphibian and arthropod communities showed variable species-specific responses, often in association to changes in DWD volumes. Challenges to maintaining long-term ecological studies of this type include continuity of funding and researchers, shifts in project scope and objectives, data management, and site coordination among research teams.

KEYWORDS: Alternative silviculture treatments, expanding gaps, Acadian ecoregion, long-term experiments, Maine.

INTRODUCTION

Silviculture is inherently a long-term proposition. Dynamics within forests exist on temporal scales of decades to centuries; therefore, any impacts that silvicultural prescriptions have must be measured over similar periods of time. Prescriptions that convert a stand from a tree species assemblage or a particular age structure to another may need even longer time frames for evaluation. Long-term, replicated research documenting the effects of silvicultural prescriptions is rare, particularly in the Acadian ecoregion of northern New England and the Canadian Maritime Provinces.

The Forest Ecosystem Research Program (FERP) is one attempt to fill this void. FERP was initiated partially in response to the “New Forestry” paradigm that began in the late 1980s in the Pacific Northwest and that Seymour and Hunter (1992) later developed into the Triad concept of forestland allocation. Under the Triad concept, land was allocated to three primary uses: (1) 10 to 20 percent of the landbase was allocated to a system of representative reserves intended to address biodiversity concerns and provide a benchmark for comparisons with managed forests; (2) 10 to 20 percent of the landbase was dedicated to high-yield silviculture, partially to offset the timber production capacity lost to reserves; and (3) the remainder of the landbase was to be managed extensively by using silvicultural systems designed to emulate natural disturbance regimes (see Seymour, this volume). The Triad concept was appealing. Land managers and conservationists could promptly identify reserve areas and silviculturists could easily design systems that would lead to higher yields. Furthermore, the long-term (>50 years) silvicultural research by the USDA Forest Service at the Penobscot Experimental Forest (PEF) provided some guidance on how traditional even-aged and

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uneven-aged silvicultural systems might be applied to portions of the landbase (Brissette 1996). Unfortunately, the Triad concept lacked scientific rigor for application. Many of these traditional systems had inherent weaknesses that could make them infeasible or impractical for broader management of the matrix. For example, many even-aged systems, although economically appealing, could not adequately create the stand structure that would mimic the gap-driven natural disturbance regimes of the Acadian ecoregion. Selection systems might create this structure, but often they were unwieldy in application, expensive, and in some respects, as artificial as even-aged systems. Research with hybrid silvicultural systems, those combining the strengths of both even-aged and uneven-aged systems, was needed.

In 1994, a group of faculty members from the University of Maine received a 5-year grant from the Maine Agricultural and Forest Experiment Station to help fill this knowledge gap. Funding for FERP beyond the initial 5 years continued at the discretion of the Dean of the College of Natural Sciences, Forestry, and Agriculture at the University of Maine. Once established, FERP also provided a foundation upon which extramural grants were developed and research projects superimposed.

FERP treatments include two versions for expanding-gap silvicultural systems that are long-term in scope (i.e., 100 years) and emulate 1-percent disturbance intensity. FERP has three scientific goals:

1. Explore the potential for developing alternative silvicultural techniques and systems based on regional disturbance ecology
2. Evaluate ecosystem-scale influences of forest practices
3. Enhance understanding about forest ecosystems in the Acadian ecoregion

This paper reviews the first 10 years of FERP, including the experimental design and inventory of the treatments and significant findings from some of the research conducted at the study sites. We conclude with a discussion of planned future activities and the potential challenges faced by this long-term project.

METHODS

Study Area

The FERP study areas are located with the Penobscot Experimental Forest (PEF) near Bradley, Maine (lat 44° 52’ N, long 68° 38’ W). This 1550-ha research forest is owned by the University of Maine Foundation and managed conjointly by the University of Maine and the USDA Forest Service, Northeast Forest Experiment Station (fig. 1). This forest lies on soil types derived from glacial till and ranging from well-drained loams and sandy loams on glacial till ridges to poorly and very poorly drained loams and silt loams in flat areas between the ridges (Brissette 1996). Cover types are dominated by Acadian Region softwoods including red (*Picea rubens* Sarg.), white (*P. glauca* (Moench) Voss) and black spruce (*P. mariana* (Mill.) B.S.P.), balsam fir (*Abies balsamea* (L.) Mill.), eastern white pine (*Pinus strobus* L.), eastern hemlock (*Tsuga canadensis* (L.) Carr.), and northern white-cedar (*Thuja occidentalis* L.). Common hardwoods in these types include red maple (*Acer rubrum* L.), paper (*Betula papyrifera* Marsh.) and gray birch (*B. populifolia* Marsh.), and quaking (*Populus tremuloides* Michx.) and bigtooth aspen (*P. grandidentata* Michx.). Natural stand structures in this region are typically uneven-aged and quite diverse with windstorms and insect epidemics as the major disturbance events (Seymour 1992). Stand replacing fires are thought to occur less than once per 1000 years in these types (Lorimer 1977). Overall, disturbance intensities are estimated to be no more than 1 percent per year (Runkle 1982).

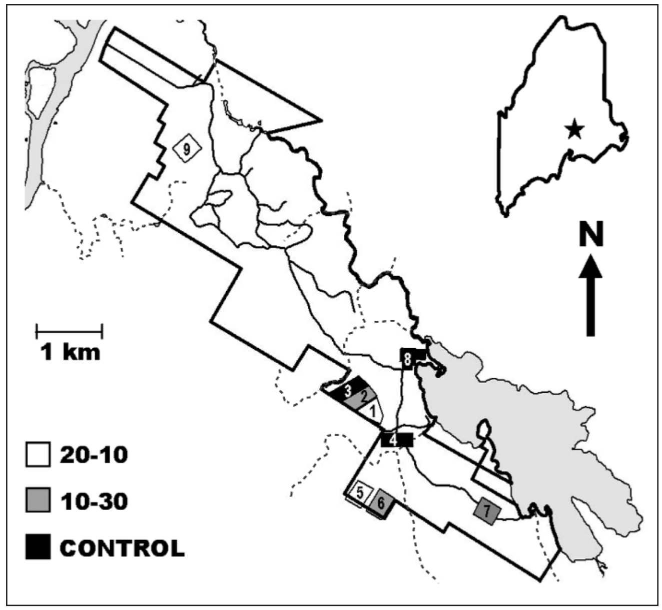

Figure 1—Location of the Forest Ecosystem Research Program research areas (RA) within the Penobscot Experimental Forest in Bradley, Maine. Block 1 (consisting of RAs 1-3) was initially harvested in winter 1995-1996, block 2 (RAs 4-6) was harvested winter 1996-1997, and block 3 (RAs 7-9) was harvested winter 1997-1998. Permanent roads are shown with solid lines; dotted lines indicate streams.

Table 1—Description of the three treatments being studied within the Forest Ecosystem Research Program at the Penobscot Experimental Forest in Bradley, Maine

Treatment	Disturbance intensity (yr^{-1})	Permanent retention tree	Cycle for complete regeneration	Compositional goal
20-10	2% (first 50 yr) 0%(second 50 yr)	10% basal area	50 yr (w/ 50 yr rest)	mid-successional
10-30	1%	30% basal area	100 yr	late-successional
Control	natural	100% basal area	natural	natural succession

Experimental Design

The FERP study was established between 1995 and 1998 across nine 9.4- to 11.3-ha research areas within hardwood-dominated mixed wood sites on the PEF. The design is a randomized complete block with three replicates each of two silvicultural treatments and an unharvested control, blocked on the year of winter harvest (fig. 1). The two silvicultural treatments were derived from the German *Femelschlag* or expanding-gap silviculture (fig. 2a). The heavier "20-10" treatment removed approximately 20 percent of the canopy at each entry (range: 19.5 to 21.3 percent, assuming 5 m wide skid trails), with 10 percent of the basal area permanently reserved. The lighter "10-30" treatment removed 10 percent of the canopy each entry (range: 6.2 to 13.8 percent), with 30 percent of the basal area permanently reserved. Both treatments have 10-year cutting cycles, 100-year rotations, and emulate 1-percent disturbance intensity; the 20-10 treatment differs by concentrating harvest activity within the first 50 years and then allowing the stand to rest for the second half of the rotation (table 1). Natural gaps and current age structures are used to help adjust cutting levels; for example, the 10-percent goal in one replicate of the 10-30 treatment was adjusted downward because of a large patch of very young (<20 yr) regeneration that existed in a significant portion of the stand. Harvests should create quite diverse age structures and canopy conditions as successive gap expansions regenerate new cohorts of individuals (fig. 2b). Reserve trees, selected to protect rare species, maintain species diversity, improve species and genetic composition of regeneration, retain or increase wildlife value of stand (i.e., current cavity trees or future large-diameter downed woody material), and/or greatly increase in value over an extended rotation (e.g., white pine), would add further structural complexity to the resulting stand (fig. 2b). After one rotation, the surviving reserve trees from the initial harvest are either selected for continued reserve, or harvested and replaced with newly selected reserves.

Within each research area, two sets of inventory plots are used. The first set is designed to inventory overall treatment effects on stand conditions (i.e., growth and yield of the resulting stand). Twenty 0.05 ha fixed area, circular inventory plots were randomly chosen from the intersection points of a 50 m x 50 m grid laid across each research area. All overstory trees (>9.5 cm d.b.h.) and deadwood (>9.5 cm small-end diameter) are inventoried. Nested within, saplings (>1.5 cm d.b.h.) and all seedlings/herbaceous species are inventoried with 0.01 ha fixed area, circular plots and four 1 m^2 quadrats, respectively. Light conditions also are measured within the plots using the LAI-2000 Plant Canopy Analyzer (LI-COR 1992). The second set of inventory plots assesses treatment effects on vegetation dynamics and development of the regeneration within harvested gaps. In both natural (as in control research areas) and harvested gaps, transects were laid along the longest north-south axis. Along each transect, 2 m x 2 m quadrats are placed every 4 m, starting at 2 m north and 2 m south of gap center, and extending to the edges of the gap. Abundance and cover of all herbaceous and woody species, basal area of the residual canopy and light levels are measured in each quadrat. Further details of sampling protocols are available from the authors.

RESEARCH FINDINGS

The FERP harvest treatments created diverse canopy conditions that have provided numerous graduate students and scientists with opportunities to investigate the effects of gap creation on the forest biota. A major emphasis of this research has been the quantification of harvest effects and interactions between downed woody debris (DWD; Fraver et al. 2002), terrestrial amphibians (Strojny 2004), and forest arthropods (Thomas, n.d.). Other studies have examined gap influences on herbaceous vegetation and tree regeneration (Schofield 2003), and bird communities (Hartley 2003). The FERP research areas also have been invaluable for teaching and outreach at the University of Maine.

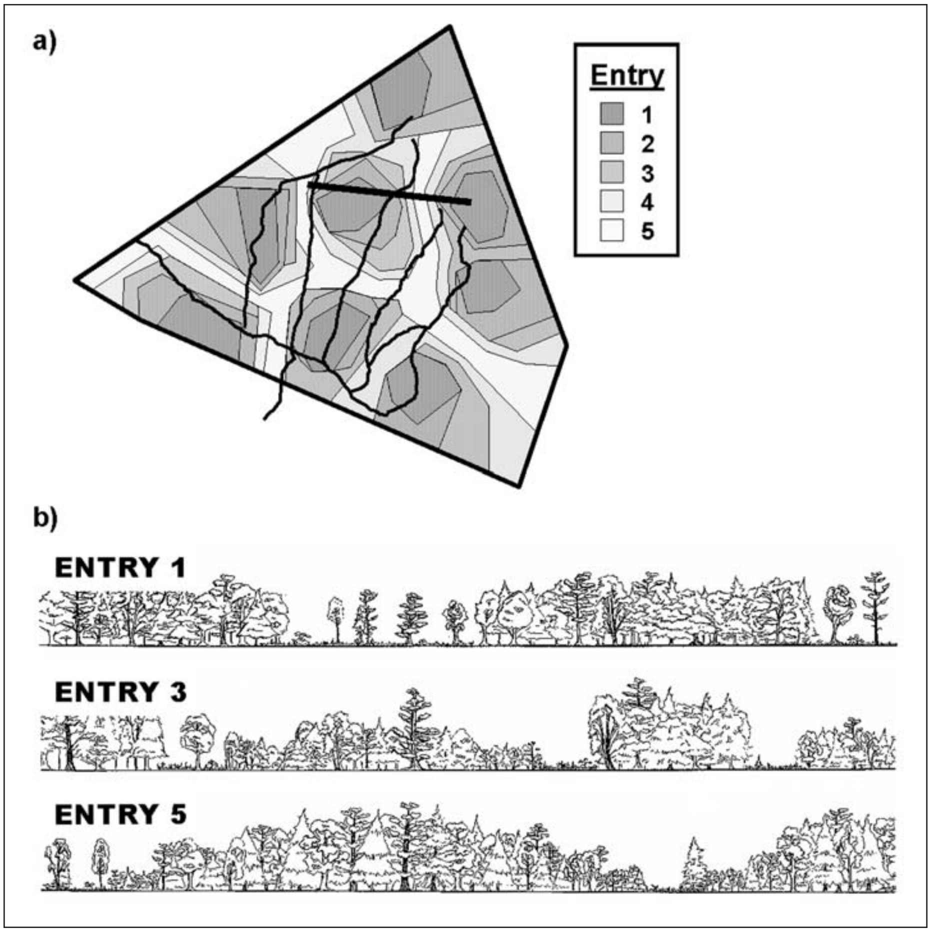

Figure 2—Hypothetical example of the 20-10 harvest expanding-gap treatment. Each entry removes 20 percent of the area, leaving 10 percent of the basal area in reserve trees (fig. 2a). The expected structural development of the stand after entries 1, 3, and 5 (fig. 2b) marked by the heavy black line in figure 2a is quite complex and diverse, consisting of multiple cohorts and canopy layers of trees and reserves. The existing skid trail network is shown as light black lines in figure 2a.

Downed Woody Debris

Preharvest volume and biomass levels of DWD were approximately 109.1 m^3/ha and 23.2 Mg/ha, respectively (Fraver et al. 2002). Initial gap harvesting contributed a pulse of small-diameter, less-decayed pieces into the DWD distribution, with the 20-10 treatment adding significantly more than the 10-30 treatment ($p = 0.069$). Fraver et al. (2002) also suggested that temporal development of DWD in many Acadian Region forests may not follow the typical U-shape that has been reported elsewhere, often in much more even-aged systems.

Nutrient analysis of this work (Saunders, n.d.) indicates that DWD from hardwood species generally had higher nutrient content than from softwood species in comparable decay classes. Not surprisingly, preliminary results suggest that harvesting shifts nutrient loads from live biomass to less decayed DWD classes. However, as in many forest communities in the Acadian Region, the nutrient loads in DWD are insignificant compared to those in living tree biomass and soil pools (Fernandez 2004). Therefore, it is unlikely that the shift of nutrients to DWD from harvest constitutes a significant change in nutrient pools or imposes any limitations on forest productivity at the site scale.

Terrestrial Amphibians

Most terrestrial amphibian species studied on FERP research areas have not been influenced by natural or harvested forest gaps. Strojny (2004) studied amphibian communities using pitfall trap arrays over 2 years and 250,000 trap nights. She concluded that of 12 species, only juvenile and adult spotted salamanders (*Ambystoma maculatum* Shaw) showed a consistent, negative population response to gaps. However, she did find during active searches of moderately-decayed class II-III logs under a closed forest canopy that northern red-backed salamanders (*Plethodon cinereus* Green) were present in about 40 percent of all logs greater than 10 cm diameter (small-end). In gaps, the detection rate varied by log size, ranging nearly linearly from about 6 percent for 10 cm logs to over 50 percent for 45 cm logs. This suggested that salamanders shifted their habitat preference to larger diameter logs in response to the harvest gaps. This observation is similar to one by Mathis (1990), who found that red-backed salamanders preferred larger cover objects that would buffer them against extreme temperatures.

Forest Arthropods

In one of first large-scale studies of forest click beetle (Family: Elateridae) communities, Thomas (n.d.) investigated the interactions among harvested gap size and DWD on click beetles. As of the 2002 field season, 42 species have been identified, five of which were unknown to science. Preliminary results suggest that although the click beetle community as a whole occupied the full size range and all decay classes of DWD present, most species were specialists in terms of DWD size (diameter), DWD decay class, and/or harvest gap size—even those species reported as generalists elsewhere in the literature. Harvests had species-specific effects on the community, usually through its influence on the DWD distribution. Overall, soil emergence of click beetles (individuals/m^2) was higher in non-gap areas ($p<0.01$) versus gap areas of the same harvest treatment, but the different silvicultural treatments themselves were not significant ($p = 0.84$). This indicated that click beetle community responded negatively to the presence of any gap, whether or not that gap was natural or harvested. With the exception of two species, DWD diameter had no effect on click beetle emergence from logs. Decay class of DWD did affect beetle emergence, however, with more beetles emerging from well-decayed class IV logs than from moderately-decayed class II logs ($p = 0.03$; Thomas, n.d.).

Gap Vegetation and Tree Regeneration

Gap harvests influenced herbaceous community dynamics and had mixed effects on tree regeneration. Schofield (2003) reported that although larger, harvested gaps (>500 m^2) had greater average percentage of cover and overall plant species richness, diversity and evenness indices did not differ between smaller gaps, either harvested or natural, and closed-canopy conditions ($p = 0.74$ and $p = 0.72$, respectively). The most significant change in plant communities was an increase in the abundance of ruderal and exotic invasive species in the gaps of the 20-10 treatment.

Although the FERP harvests had no significant effect on total number of regenerating trees ($p = 0.15$), they did cause a shift in species dominance (Schofield 2003). Harvested gaps tended to have higher numbers of red maple and paper birch in all height classes. Conifers dominated the natural gaps more, with balsam fir, eastern hemlock, and eastern white pine being the predominate species. Regeneration under closed canopies was more indicative of the overstory species, with balsam fir, red and sugar maples (*Acer sacharrum* Marsh.), and eastern hemlock more common, particularly in the larger height classes (>2.0 m tall) (Schofield 2003).

Forest Bird Communities

Hartley (2003) studied the response of the forest bird community to the FERP gap-harvests from 1995-1998. Depending on the timing of the initial harvest in a block, a census of the avian communities in each research area was done 1 to 3 years before and 1 to 3 years after harvest. No significant changes in community composition, species richness, or density were detected, and interestingly, few pioneer bird species were captured. These responses may result from the small size of the research areas, or from the relatively narrow range of the gap sizes created (110 to 2170 m^2). Patterns may change greatly after the next gap-expansion harvests in 2005-2008.

ACTIVITIES AND CHALLENGES

Although FERP has increased our understanding of the Acadian forest over the past 10 years, it faces challenges common to most young, long-term silvicultural studies. First, as the study progresses, modifications beyond the original treatment design may become necessary. For example, expanding gap systems may run into a "bottleneck" several cycles out when expansions around existing gaps become so narrow as to be inoperable and/or residual patches of trees become susceptible to wind throw. In the 20-10 treatment, this does not become a great issue until the final cycle (fig. 2a); however, in the 10-30 treatment this will be a greater problem. Expanding the gaps asymmetrically in later entries (and thus more closely approximating a group selection harvest system) may alleviate some of these concerns.

Sampling design continues to be a challenge. Our inventory system, like many other long-term silvicultural experiments, was originally designed to collect growth and yield data for the research area as a whole. This approach has proven inefficient, however, when trying to detect the influence of harvesting on vegetation dynamics within the gaps because no more than two of the 20 inventory plots in each research area occur within gaps in the 10-30 treatment. Therefore, a system of transects was installed in each expanding gap to alleviate this problem. In addition, spatially explicit questions are becoming more important. For example, how do gaps and skid trails affect the distribution of DWD, and the resulting salamander and arthropod habitat, across each research area? We are moving toward more spatially-explicit sampling designs to help address these types of questions. For example, the next set of FERP inventories will use line-transects rather than plot censuses to inventory DWD and snags across each research area.

Continuity of funding is always a concern. Since 1995, the FERP operating budget has been reduced and can no longer support the full suite of measurements that had been initially collected. Adjustments to the sampling methods have been incorporated to improve efficiencies and reduce costs (e.g., changing DWD sampling). However, a periodic infusion of extramural funding will likely be needed to maintain the study.

Lastly, continuity of personnel in long-term, university-sponsored research is a persistent challenge. Unlike the long-term silvicultural experiments conducted by the U.S. Forest Service at the PEF, which have permanent technical support, FERP is maintained largely by graduate students. Fortunately, the Department of Forest Ecosystem Science has dedicated a graduate research assistantship to FERP. As a result, three successive Ph.D. students have been able to coordinate field activities for the program. As the study progresses, however, increasing demands for data management and field coordination among interdisciplinary research teams will strain available graduate student time. Time saving protocols such as using logic checks during data collection, as well as making the database spatially explicit within a GIS, may help reduce this burden.

CONCLUSION

After 10 years, FERP has completed 10 percent of its planned lifespan. FERP has been successful thus far because of consistent support from the College of Natural Sciences, Forestry, and Agriculture and Department of Forest Ecosystem Science at the University of Maine. FERP has created diverse forest conditions in a replicated experiment that can help interdisciplinary research teams answer pressing questions about the Acadian forest. As FERP approaches its second decade, however, it enters a period where many long-term experiments fail. Sometimes this failure results from a loss in interest in the original research questions as scarce funding moves to support newer and more exciting investigations. In other cases, the experiment is unfairly discredited because not enough time has passed to demonstrate the scientific value of the study. A key lesson learned in the most successful long-term experiments is that it generally requires a tenacious and persistent researcher to carry an experiment through these difficult years!

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Seeking Alternatives to Clearcutting in British Columbia: The Role of Large-Scale Experiments for Sustainable Forestry

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ABSTRACT

Numerous large-scale, forest management experiments have been established in British Columbia as part of a government response to public protests over clearcutting. The experiments test the effect of opening size and concepts such as aggregated and dispersed retention, on an operational scale with experimental units usually exceeding 10 hectares. Most of the experiments are multidisciplinary in scope and, in some cases, they are interdisciplinary in practice. The short-term outputs from these experiments have been substantial. A few have led, directly or indirectly, to major shifts in operational practice. The initial surge of funding has now ended, however, despite these accomplishments. We describe several lessons learned in British Columbia that might have application in future programs with similar ambitions.

KEYWORDS: Clearcutting, forest management experiments, British Columbia.

INTRODUCTION

In 1990, public forestland management in British Columbia, which covers an area of about 25 million hectares (ha), was undergoing severe criticism from environmental groups and the public. This was primarily because of the almost universal use of clearcutting to harvest timber. The criticism focused on the cutting of "big trees" in the temperate rain forest of the southern coast, but echoes of the controversy were heard throughout the province. Although the use of clearcutting was vigorously defended by industry groups, forest professionals, and the government of the day as the safest and most efficient practice, the need for some change was also acknowledged. Part of that change was a government initiative headed by the Ministry of Forests to examine and develop alternative methods of harvesting for forest types throughout the province. A substantial body of research, development, and extension work grew from this Silvicultural Systems Program (Ministry of Forests 1992). As part of the program, numerous large-scale, forest management experiments were established around the southern half of the province, sampling a wide range of ecological conditions.

In this paper, we provide a brief description of the program and the long-term forest management experiments that were established under its umbrella. We draw some conclusions about the success achieved by the experiments, describe the lessons learned during their establishment, and speculate on their longevity.

BRITISH COLUMBIA'S SILVICULTURAL SYSTEMS PROGRAM

The Silvicultural Systems Program was initiated in 1990 to investigate alternatives to conventional clearcutting (defined as clearcutting in large blocks followed by site preparation and planting to create plantations). Over the 8 years of its life, from 1990 to 1998, about $17 million were spent on research, development, demonstration, and extension

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of alternatives.[4] Funding was provided first by the Provincial Silviculture Program and the Canada-British Columbia Partnership Agreement on Forest Resource Development from 1991 to 1995 and then by Forest Renewal British Columbia. Some of the research projects started under the program continue to be funded under successor funding programs.

The declared purpose of the Silvicultural Systems Program (Ministry of Forests 1992) was to encourage expansion in the range of forest harvesting practices used throughout the province. In 1988-89, 91 percent of the 270 000 ha harvested on public (crown) land was clearcut. The remaining area was cut using some variety of selection cutting, mostly by applying diameter limit cuts in the dry Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) stands of the southern Interior. Although the program did not have an explicit goal of changing the mix of forest practices within a specified time frame, the intention of change was clear. Public brochures and publications showed an idealized landscape with many forms of silvicultural systems in use from hilltop to valley bottom. Moreover, the existence of the program was used to provide the people of the province and purchasers of wood products from the province evidence of willingness to change (Benskin and Bedford 1994).

Well over 200 projects were supported over the life of the program. They ranged from long-term, multidisciplinary forest ecology and management experiments to one-day courses on such topics as even-aged partial cutting for professional foresters, and brochures describing the range of silvicultural systems for the general public. In mid-program, when expenditures peaked, about 45 percent of the funds were spent on long-term research trials, 30 percent on short-term biological and regeneration issues, 15 percent on issues such as timber pricing impediments to the implementation of clearcutting alternatives, 5 percent on extension, and 5 percent on administration. A companion initiative to the Silvicultural Systems Program was undertaken by the Ministry of Forest's Small Business Forest Enterprise Program. Government foresters worked successfully with small business operators over several years to create examples of silvicultural systems in several coast and interior parts of the province (Bancroft et al. 1997).

The program ran with substantial budgets for about 6 years, and severely reduced budgets for 2 more, before expiring amid a welter of political, institutional, and economic change. The long-term experiments initiated under the program received continuing funds from new funding sources for several more years until very recently, when a number of them have suffered funding cutbacks.

LARGE-SCALE SILVICULTURAL SYSTEMS EXPERIMENTS IN BRITISH COLUMBIA

We have documented 24 large-scale,[5] forest management experiments dealing with alternatives to clearcutting in British Columbia. They can be found throughout the southern half of the province. Two of the experiments were established many years ago, one of which was abandoned and the other recently re-established. Eighteen of the experiments were established in the course of the Silvicultural Systems Program. One has been established since the program ended. Almost all had, or have, the purpose of demonstrating alternative practices to clearcutting and compare clearcutting to some silvicultural alternatives. One examines only uneven-aged management. Several experiments were designed to examine opening size or overstory retention levels rather than textbook definitions of silviculture systems. Most consider more than timber values. They are also generally cooperative, multidisciplinary, and by necessity, interagency projects. The projects are listed in table 1, and their general location is shown in figure 1.

Major Accomplishments of the Forest Management Experiments

All of the experiments showed that at least some alternatives to clearcutting were operationally feasible. Detailed cost studies on some projects showed that some alternatives could be implemented with existing logging machinery and were not prohibitively expensive (e.g., Mitchell 1996, Phillips 1995). The experiments also showed that many of the environmental concerns regarding clearcutting were either not a concern (e.g., regeneration), or exaggerated (e.g., soil erosion and nutrient losses), at least in the short term (Arnott et al. 1995, Huggard and Vyse 2002b). These results have probably supported a reluctance to move away from clearcutting throughout the province. In 2002-03, clearcutting with reserves retained for either riparian protection or wildlife habitat was the dominant logging practice.
(text continues on page 160)

[4] Information from Ministry of Forests files available from A.Vyse (alan.vyse@gems1.gov.bc.ca)

[5] We define large-scale experiments as having treatment units larger than 1 ha.

Table 1—Large-scale experiments investigating alternatives to clearcutting in British Columbia

Name of experiment and year initiated	Ecological zone[a] and location	Treatment, size of treatment units and replications	Ecosystem response variables studied
1. Aleza Lake, 1930s to 1950s	SBS Central Interior Plateau; near Prince George	Clearcut and shelterwoods with 50% retention; no replication	Tree growth, vegetation, climate
2. Bolean Lake, 1951	MS Fly Hills; near Falkland	Clearcut, 50% retention in stripcuts, group selection, individual tree selection; 5-10 ha.; no replication	Tree regeneration, tree growth, bark beetles, windthrow Project terminated in early 1970s
3. Quesnel Highlands, 1990	ESSF Quesnel Highlands; near Williams Lake	Clearcut, group selection with 1, 0.13, and 0.03 ha openings; 3 replications	Climate; soil; tree regeneration; tree growth; vegetation; aboreal lichens; snow
4. Uniform Shelterwood, 1990	SBS Fraser Plateau; E. of Williams Lake	50 and 70% dispersed retention; shelterwood; 1.4 ha; 3 replications	Climate; tree regeneration; windthrow; vegetation, small mammals
5. Boston Bar, 1991	IDF Fraser Canyon; near Boston Bar	Clearcut, seed tree, shelterwood; 2 replications	Climate; soil; tree regeneration; vegetation; windthrow; logging costs
6. Date Creek, 1991	ICH N.W. Interior-Coast transition; near Hazleton	Clearcut, group selection with 30% removal and 60% removal; 11-38 ha; 4 replications	Soil and soil organisms; tree regeneration; aboreal lichens; vegetation; sporocarps, birds, bats, amphibians, small mammals; water; windthrow
7. Lucille Mountain and Northern Wet belt Project, 1991	ESSF/ICH Cariboo Mountains and Rocky Mountains; E. of Prince George	Clearcut, shelterwood, single tree selection; small patch cuts of 0.2 ha; 1-20 ha; no replication; 7 operational trials underway or planned in Northern Wet belt	Climate; soil; tree regeneration; tree growth; vegetation; aboreal lichens; windthrow
8. MASS, 1991	CWH Central Vancouver Island; near Campbell River	Clearcut, patch cuts, single tree retention, shelterwood; 5-40 ha; 3 replications	Climate; soil and soil organisms; vegetation; aboreal lichens; tree regeneration; birds; canopy arthropods; logging costs
9. Opax Mountain, 1991	IDF Thompson Plateau; Kamloops	80% and 50% retention, aggregated and dispersed; openings 0.1, 0.4, and 1.6 ha; 20 ha; 2 replications	Climate; soil and soil organisms; coarse woody debris; tree regeneration; tree growth; aboreal lichens; ground arthropods; vegetation; sporocarps; songbirds; woodpeckers; small mammals; snow; windthrow

Table 1—Large-scale experiments investigating alternatives to clearcutting in British Columbia (continued)

Name of experiment and year initiated	Ecological zone[a] and location	Treatment, size of treatment units and replications	Ecosystem response variables studied
10. "Beetle proofing" mature lodgepole pine, 1992	IDF/MS S. Rocky Mountain Trench; near Cranbrook	Clearcut and thinned to 4 m and 5 m spacing and fertilization; 10-20 ha; 3 replications	Climate, tree regeneration, bark beetles, windthrow, root disease, vegetation, thermal cover for mule deer, logging costs
11. Cats Ears Creek steep slopes, 1992	CWH Central Vancouver Island; near Port Alberni	75% dispersed retention and aggregated retention with 0.15, 0.3 and 1.4 ha openings; 4-7 ha, no replication	Tree regeneration; windthrow; vegetation
12. Roberts Creek, 1992	CWH South Coast; near Sechelt	10% dispersed retention; 50% aggregated retention; 5-10 ha; no replication	Climate; Soil; timber; wildlife except large animals; fungi; water; logging; worker safety costs
13. Sicamous Creek, 1992	ESSF Shuswap Highlands, South-Central BC; near Sicamous	10- and 1-ha clearcuts; array of 0.1-ha openings; single tree selection; all 33% removal; 30 ha; 3 replications	Climate; soil and soil organisms; coarse woody debris; tree regeneration; aboreal lichens; vegetation; sporocarps; ground arthropods; songbirds; woodpeckers; spruce grouse; small mammals; snow; streams; windthrow; bark beetles; logging costs
14. West Arm Demonstration Forest, 1992	ICH Kooenay Lake; near Nelson	Clearcut; seed tree; shelterwood; patch, single tree and woody debris retention; 4500 ha; operational trials only; no replication	Climate; soil; coarse woody debris; tree regeneration; vegetation; water quality and quantity
15. Westwold, 1992	IDF Okanagan Plateau; near Kamloops	15, 20 and 25 m^2 basal area retained; 2 Q values; 1 ha; 3 replications	Tree regeneration; tree growth
16. Mount Seven/ Ice Road, 1993	ICH Columbia Mountains; near Golden and Nakusp	Clearcut; low dispersed retention 30%; high dispersed retention 50%; 1 ha; 4 replications	Climate; soil; coarse woody debris; tree regeneration; tree growth; vegetation; root disease
17. Itcha/Ilgachuz Alternative Silvicultural Systems, 1994	SBPS/MS Chilcotin Plateau; W. of Williams Lake	Clearcut 50% aggregated retention with stems or whole trees removed, 70% retention stems only; 6-10 ha.; 5 replications; two additional operational trials	Climate, soil, tree regeneration; tree growth; vegetation, terrestial and arboreal lichens, bark beetles, dwarf mistletoe, sporocarps, windthrow, wildlife, snow

Table 1—Large-scale experiments investigating alternatives to clearcutting in British Columbia (continued)

Name of experiment and year initiated	Ecological zone[a] and location	Treatment, size of treatment units and replications	Ecosystem response variables studied
18. Bald Range, 1995	MS Okanagan Plateau; near Summerland	Regenerated clearcut; 36% retention and uncut; Retrospective study on effects of retained structures; >10 ha; 3 replications	Small mammals, vegetation
19. Fort Nelson Mixedwoods, 1996	BWBS Near Fort Nelson	Group shelterwood with .13 and 1 ha. openings; 4 replications	Snags and coarse woody debris; light; vegetation; tree regeneration
20. Rennell Sound steep slopes, 1996	CWH Graham Island, Queen Charlotte Island	Clearcut, 50 and 70% aggregated retention, 70% dispersed retention; 5-10 ha; 2 replications	Tree regeneration; windthrow; vegetation; logging costs
21. Viewland Mountain, 1996	ICH Quesnel Highlands near Williams Lake	20% removal; group selection; 0.25-2 ha openings; no replication	Mule deer; tree regeneration; climate; vegetation; root disease; bark beetles; windthrow; logging costs
22. HYP[3] –Pattern Process and Productivity in Hypermaritime forests, 1997	CWH NW Coast; near Prince Rupert	Diameter limit logging of low productivity timber; 50 ha; 2 replications	Soil; tree regeneration; vegetation; logging costs; water
23. Mount Tom Adaptive Management Trial, 2000	ESSF Quesnel Highlands near Williams Lake	Group selection 33% removed; 0.1-3 ha openings; >10 ha; 9 replications	Mountain caribou; arboreal lichens; tree regeneration; windthrow; vegetation; snow; logging costs
24. STEMS – Silviculture Treatments for Ecosystem Management in the Sayward, 2000	CDF/CWH Central Vancouver Island; near Campbell River	Clearcut, patch cut, group selection, aggregate retention, dispersed retention, commercial thinning; 3 replications	Climate; tree regeneration; tree growth

[a] Ecological zones are described in Meidinger and Pojar 1991.

BWBS= black and white boreal spruce; CDF= coastal Douglas-fir; CWH= coastal western hemlock; ESSF= Engelmann spruce-subalpine fir; ICH= interior cedar hemlock; IDF= interior Douglas-fir; MS= montane spruce; SBS= sub-boreal spruce; SBPS= sub-boreal pine spruce.

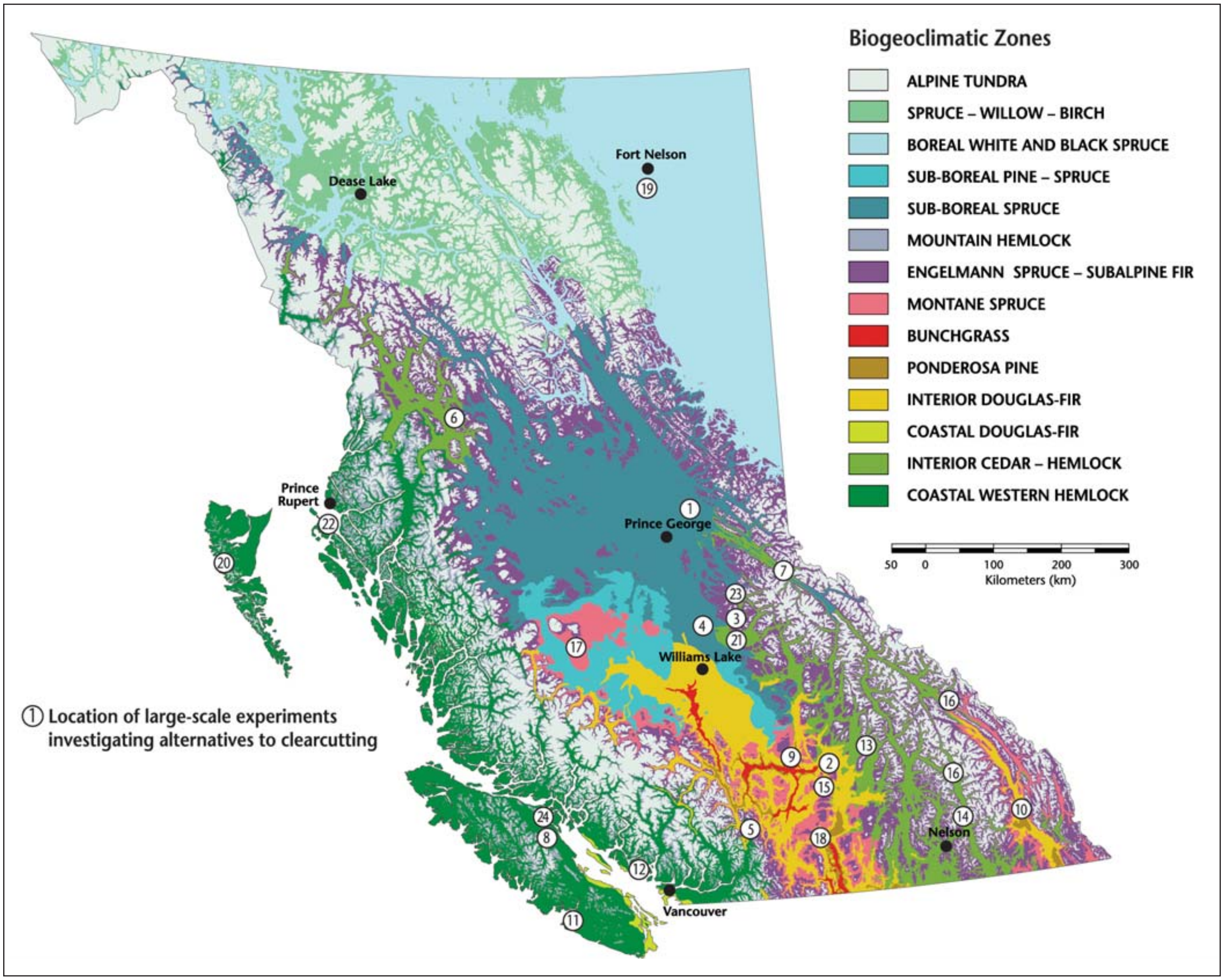

Figure 1—Location of silvicultural systems trials in British Columbia.

However, on the lower coast, where social pressures were most intense, the Montane Alternative Silviculture Systems (MASS) project led, directly or indirectly, to large-scale changes in operational practice. There the predominant cutting method changed from clearcutting to variable retention. In the Interior, the Quesnel Highlands and Itcha/Ilgatchuz Alternaive Silviculture System projects have led to changes in operational practice to a group selection treatment based on protecting habitat for the endangered mountain eco-type of the woodland caribou (*Rangifer tarandus caribou*).

The more comprehensive trials have shown that all alternatives have some negative effects on components of the forest ecosystem. As a consequence, they provide support for the adage "don't do the same thing everywhere." Widespread application of a single practice is unlikely to be sustainable. These trials have also provided information on how negative effects could be mitigated. Edge effects associated with openings were shown to be less intrusive than previously thought. For example, at Sicamous Creek, edge effects for many variables were no more than half a tree height into the forest or into the opening (Huggard and Vyse 2002a). Windthrow, which is always raised as a major concern by operational foresters in any discussion of alternatives to clearcutting, was shown to be damaging no matter what system was used, but less damaging than expected at least in the province interior. In addition much information was gained on the response of tree seedlings to light environments and to site preparation. And the response of little-studied elements of the forest ecosystem to forestry practices, such as small mammals, invertebrates, soil organisms, lichens and mosses, was recorded.

Most of the experiments have been measured at least once since the treatments were imposed. Some elements, such as tree seedlings and windthrow, have been measured several times. And in the case of a few readily assessed ecological indicators, such as seedfall and songbirds, measurements have been made annually. Although this is a substantial achievement, much more needs to be done. We expect that some responses will take much longer than a decade to manifest themselves, and we also expect that there will be changes in response over time. One example is the invasion of an experimental site by ants and pocket gophers that may have been attracted by the disturbance created by cutting openings. Their interaction with other established organisms on the site is unknown.

The scientific output of the program has been substantial. About 80 journal articles have been published to date, and more appear every year. There are also many more publications in agency publication series. However the output is very uneven. Three projects account for 90 percent of the journal articles (Sicamous Creek, Date Creek and MASS).

Forest researchers are often accused of failing to communicate the results of their work to operational foresters. However, in the case of the Silvicultural Systems Program, the possibility of communication failure was dealt with from the beginning. Researchers were encouraged to discuss the findings of their work at formal and informal gatherings of practitioners. Extension notes were produced to apprise practitioners of the latest findings and who to contact for more details. Specific courses on silvicultural systems were designed and delivered through the Forestry Continuing Studies Network and the Silviculture Institute of British Columbia. Summary documents were prepared for professional and public audiences alike.

Some Lessons From the British Columbia Experience

The British Columbia experience in establishing numerous large-scale forest management experiments in a short period offers several lessons for future efforts of this magnitude. We have summarized these lessons as seven rules for success.

1. Foster strong project leadership and succession. Projects without effective and committed leadership will flounder and continuity will be threatened. Good leaders promote, coordinate, synthesize, integrate, and plan for all of the research initiatives.
2. Engage operations in research. Project establishment and continued measurement is expensive, and planning experiments with operational partners is essential. Constant communication with operational foresters can help maintain interest in the experiment results, but it does not guarantee continued support.
3. Plan multidisciplinary and interdisciplinary experiments. Given the pace of societal change, issues of relevance today may not be the issues of pressing concern a decade from now. An ecosystem approach provides a route around such difficulties, and there can be economies with investigating many ecosystem responses at once, but the absolute cost is high. Although there are advantages to imposing a common sampling scheme on an experiment, such a scheme does not guarantee interdisciplinary work. The risk of failure may be higher in interdisciplinary work.
4. Plan your project scale and scope carefully within your expectations of future resources. Projects at a single location may have limitations, but the cost of servicing multiple locations may prove to be an insurmountable hurdle.
5. Design robust experiments with strong contrasts. Remember that biological and statistical significance are separate concepts. Given that the cost of establishment is high and the pace of institutional change is rapid, only experiments that have strong contrasts and highly visible results are likely to have continued scientific and operational appeal.
6. Maintaining relevance leads to longevity. Plan for short-term outputs from long-term projects to keep your project in the eye of funding agencies and supporters. However, operational relevance can differ strongly from scientific relevance. This has become a problem in British Columbia where funding agencies have required applicants to promise operational change through research results. Scientists control neither the rate nor direction of change, and this is doubly true for forest scientists who must cope with extremely long periods over which change is measured and assessed. They can contribute knowledge and elevate the understanding of practitioners, but these are rarely compelling forces for change. The increasing demand for scientifically credible forest management activities, backed by certification, may help close the gap between operational and scientific

relevance, but fundamental differences mean that regular communications between project scientists and sponsoring forest managers are essential.

7. Protect your investment. Scientists are sometimes uncomfortable with promoting their efforts, but promotion of your experiment is essential. Seek a trade mark for your experiments and publicize your efforts whenever possible. However, even these efforts may fail and funding may dry up. Recognize from the outset that specific research funding efforts rarely last 5 years. Build a "sleep mode" into projects so you can ride out periods of low funding. Make sure you have data protection and management protocols that enable the project to be successfully resuscitated after hibernation.

CONCLUSIONS

Long-term forest management experiments examining alternatives to clearcutting in British Columbia have shown, and communicated clearly, that there are many advantages to alternatives. They have also demonstrated that the many supposed negative effects of clearcutting are either exaggerated or without foundation. But they have not provided any compelling reasons for adopting a wider range of forestry practice. This may be why these projects are now stuck in a funding backwater. Their individual contributions are valued, the need for long-term research is acknowledged, but their upkeep is expensive, and other priorities beckon. This outcome should not have come as a surprise to the scientist engaged in the projects. There are numerous examples of similar projects in British Columbia and elsewhere that have met a similar fate (Smith 1993).

How do we change this less than encouraging picture? For those charged with the responsibility of funding forest research and determining priorities, there has to be acknowledgement that research results and their communication are not the most important elements leading to change. The British Columbia experience suggests that success defined as changing practice or making an economic contribution is impossible to predict amid a welter of rapidly changing social and economic factors and events. Research success, so defined, has little to do with sound scientific practice or the communication skills of scientists. If this observation is generally sound, then the focus of research programs has to change. Short-term expectations of individual projects should be much less important than the long-term expectations, with respect to the whole portfolio of efforts to improve forestry practice. This is especially true in British Columbia where the landscape and forest ecosystems are so varied, and public concerns about the management of public lands are so volatile.

For forest scientists, we suggest that working together to promote the concept of long term funding for long-term projects might be fruitful. We need to find a way of keeping the forestry community's feet to the fire. Everyone acknowledges the need for a long time horizon in forestry and the need for long-term research, but no one seems willing to pay despite the low cost. Even at its funding peak, the annual cost of the Silvicultural Systems Program was less than 1 percent of the stumpage value of logs removed from public lands. In British Columbia we have been developing the concept of Living Forest Laboratories, supported by an endowment or endowments. We propose to promote the concept of long-term forest experiments to the funding agencies and the public using the familiar idea of scientific laboratories (de Montigny et al. 2004). If the public is willing to support building very expensive laboratories for cancer research, perhaps they might also be willing to support much lower cost living forest laboratories for forest management research.

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Are Landscape-Level Effects More than the Sum of Stand-Level Effects in the Missouri Ozark Forest Ecosystem Project?

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ABSTRACT

The Missouri Ozark Forest Ecosystem Project (MOFEP) is a large-scale, long-term experiment that tests the effects of even-aged management (EAM), uneven-aged management (UAM), and no-harvest management (NHM, control) on upland forest components. We evaluated pre- (1994, 1995) and post-treatment (1999, 2000) changes for ground flora species richness, percentage of ground cover, and relative cover of seven life-form groups collected from 645 permanent plots. Analyses were conducted at two levels: (1) following the experimental model using landscape-level data in an analysis of variance design, and (2) using stand-level data to determine if changes in treated sites were confined to harvested plots only. Significant landscape-level treatment effects were observed for species richness and the relative cover of annual/biennial species, woody vines, and legumes. Mean species richness per plot decreased significantly in NHM sites and increased slightly in both EAM and UAM sites. The relative cover of annual/biennial species and woody vines increased in all sites; in all cases, more so for harvested sites than NHM sites. The relative cover of legumes decreased in harvested sites, and increased slightly in NHM sites. At the stand-level, no differences were observed for any response variable between NHM sites and uncut plots on harvested sites. In plots directly impacted by timber harvests, species richness increased, cover increased dramatically, relative cover of annuals/biennials, graminoids, and woody vines increased, and relative cover of legumes decreased. The magnitude of these changes was strongly related to the created gradient in canopy openings. Almost all life-forms exhibited significant differences in relative cover between clearcut and NHM plots.

KEYWORDS: Even-aged, ground flora, Missouri Ozark Forest Ecosystem Project (MOFEP), silviculture, uneven-aged.

INTRODUCTION

Management objectives for Missouri's public and private forests are very complex and include the maintenance of ecosystem processes, conservation and restoration of habitat for Neotropical migrant songbird, small mammal, and herpetofaunal communities, creation of forests with old-growth attributes, and extraction of commodities (Missouri Department of Conservation 1986). Management decisions to integrate these complex objectives are often based on local or stand-scale habitat characteristics (Chen et al. 2002). Traditional silvicultural, stand-level research and within-patch explanations may be inadequate for many ecological phenomena, however, where broad-scale landscape perspectives are needed (Franklin 1993).

The Missouri Ozark Forest Ecosystem Project (MOFEP) is a multidisciplinary, long-term, landscape-scale experiment replicated and monitored through time to determine cause-and-effect relationships among management alternatives on multiple forest ecosystem components and to detect how the profile of these effects changes over time (Sheriff and He 1997, Walters 1993). Specifically, MOFEP tests effects of even-aged (EAM), uneven-aged (UAM), and no-harvest (NHM) management practices on the flora and fauna of upland oak ecosystems (Brookshire et al. 1997). MOFEP

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consists of nine sites (landscapes) that range from 312 ha to 514 ha and contain between 41 and 71 stands each and is thus suited to address landscape-level questions.

There is growing concern that timber harvesting may have deleterious effects on the long-term maintenance of species diversity and composition (Burton et al. 1992). Because the ground flora represents the majority of plant species in many forest communities (Thomas et al. 1999), any evaluation of different silvicultural treatments must consider changes to the species composition of the ground layer vegetation (Jenkins and Parker 1999). How and to what extent a gradient of harvest intensities and canopy openings alters the ground flora structure and composition is uncertain. Although MOFEP is designed to test hypotheses primarily at the landscape-level, evaluating treatment responses at finer scales may give better insights into the processes that are ultimately responsible for the observed effects. In this paper, we tested the hypothesis that different silvicultural treatments can rapidly induce changes in species richness, cover of ground-layer vegetation, and relative cover of several ground flora life-form groups (e.g., forbs, graminoids, shrubs, etc.) in upland oak communities in the Missouri Ozarks. We report on the short-term changes of the ground-layer vegetation at both stand- and landscape-levels in response to the first round of timber harvesting.

METHODS

Study Area

The study sites in the Current River Hills Subsection of the Ozark Highlands are located in Carter, Reynolds and Shannon counties of southeastern Missouri (lat 37°00' to 37°12'N and long 91°01' to 91°13'W). The area is characterized by a humid, continental climate, with hot, humid summers and cool winters. Mean annual temperature is 13.3°C. Average annual precipitation is 112 cm with most rain falling in spring and summer (Chen et al. 2000). Sites have primarily mature, second-growth oak-hickory and oak pine forests with relatively closed canopies. Common overstory trees include black oak (*Quercus velutina* Lam.), white oak (*Quercus alba* L.), scarlet oak (*Quercus coccinea* Muenchh.), post oak (*Quercus stellata* Wang.), shortleaf pine (*Pinus echinata* P. Mill.), black hickory (*Carya texana* Buckl.), mockernut hickory (*Carya tomentosa* Mill.), and pignut hickory (*Carya glabra* Mill.). Flowering dogwood (*Cornus florida* L.), blackgum (*Nyssa sylvatica* Marsh.), and sassafras (*Sassafras albidum* Nutt.) are common understory trees and shrub species. Most overstory trees on the sites range from 50 to 70 years old; trees older than 100 years occur on all sites, and a few trees are older than 140 years.

Experimental Layout and Silvicultural Treatments

The nine MOFEP sites form a randomized complete block design with three replicates of three silvicultural systems (even-aged management (EAM), uneven-aged management (UAM), and no-harvest management (NHM, see Sheriff and He 1997). Stands located in EAM sites are subject to no-cutting treatment, thinning treatment, or the clearcut with reserves harvest treatment. About 10 percent of the acreage in a site is or will be clearcut every 10 to 15 years for forest regeneration, and thinnings are implemented to improve tree quality and growing space of residual trees (Kabrick et al. 2002). Cutting rotations are about 100 years, with 10 percent of each site left to develop toward old-growth, reserved from harvest. Stands in the UAM sites are subject to no-cutting treatment, the single tree selection harvest treatment, or the group selection harvest treatment. A combination of single tree and group selection is implemented to improve stand quality, regulate tree size distribution (single tree selection), and create canopy gaps large enough to regenerate shade-intolerant or intermediately-tolerant tree species such as most oaks and shortleaf pine (group selection). Group openings are 21 m on south-facing slopes to 43 m in diameter on north-facing slopes (Law and Lorimer 1989). Negative exponential diameter distributions defined with the residual basal area (i.e., B-level stocking after Roach and Gingrich (1968)), the largest tree diameter (i.e., desired sawtimber size objective for an identical EAM site), and q-factor (i.e., about 1.5 for trees >11 cm d.b.h.) were used to control stocking. The diameter distribution for large trees of UAM is thus identical to the composite size class distribution across the EAM sites. Approximately 10 percent of each site is designated as old-growth reserve. The total area of group openings was to be approximately 5 percent of the harvested area in UAM sites. Vegetation plots in the NHM sites do not receive timber harvesting, serving as control replicates for the experiment and providing information on changes due to natural disturbances in upland Ozark forests in the absence of active management (for more detail on the prescriptions, see Brookshire et al. 1997).

Field Inventory

A total of 645, 0.2 ha permanent vegetation plots (70 to 74 plots per site, at least one per stand) were monitored for changes in vegetation following harvest treatments. Within each of the permanent plots, 16 one-meter square subplots were established in which all herbaceous and woody plants <1 m tall were identified to species and assigned estimates of percent live foliar coverage. Nomenclature follows that of Steyermark (1963).

Pretreatment data were collected during the summers of 1994 and 1995. Timber harvest treatments were applied in 1996. A total of 455 plots received no harvest treatment, 79 received single-tree selection, 33 were thinned, 45 received group-openings, and 22 were clearcut. Post-treatment data were collected in the summers (June through August) of 1999 and 2000. Sites were sampled in the same order and during the same 2- to 3-week period each year to avoid potentially confounding seasonal effects.

Calculations and Plant Groups

Plot-level species richness was the total number of species identified in each 0.2 ha plot. The mean percentage of ground cover at the plot level was total cover averaged across the 16 subplots in each plot. Each species was assigned to one of seven life-form groups: (1) annual and biennial species, (2) nonleguminous forbs, herbaceous vines, and ferns, (3) graminoids (grasses, sedges, and rushes), (4) legumes, (5) woody vines, (6) shrubs, and (7) trees. Relative cover was calculated for each species and for life-form groups as the ratio (*100) of the sum of coverage for each species or life-form group on each subplot divided by the total sum of all species coverages on that subplot. Pretreatment means were calculated as the average of 1994 and 1995 values, and post-treatments means were calculated as the average of 1999 and 2000 values. For a list of ground flora species frequency and abundance see Grabner (2000a).

Data Analysis

Analysis of variance (ANOVA) was used to test for block and silvicultural treatment effects among sites (landscape-level analyses) on changes (post- minus pretreatment values) of mean ground flora species richness, mean percent cover, and mean relative cover of life-form groups. Because there were at least marginally significant pretreatment differences in plot species richness ($p = 0.06$), cover ($p = 0.05$), relative cover of graminoids ($p = 0.03$) and woody vines ($p = 0.05$) among NHM, UAM, and EAM sites, pretreatment levels were used as covariates when analyzing changes due to the treatments. Tukey's HSD multiple-comparisons tests were used to investigate differences among treatments. ANOVA and Tukey's HSD multiple comparisons tests were also used to test the hypothesis that vegetation changes were proportional to harvest intensity (e.g., clearcut, thinning, group selection, single tree selection, and uncut plots). For these stand-level analyses, all plots in NHM sites were combined with uncut plots of EAM and UAM sites into one treatment type (uncut) after no statistically significant differences (all p-values > 0.05) were found for changes in ground-layer vegetation of any response variable among these plots. Plots within sites are not statistically independent and error estimates can thus be misleading; extrapolation of these results beyond the study sites is subsequently not warranted.

RESULTS

Treatment Effects Between Sites (Landscape-Level Analyses)

Ground flora across sites was diverse (gamma diversity >530 vascular species), but only a few woody vines, understory trees, and legumes (e.g., Tick trefoil (*Desmodium nudiflorum* L.), flowering dogwood, sassafras, Virginia creeper (*Parthenocissus quinquefolia* L.), summer grape (*Vitis aestivalis* Michx.), black oak, and hog peanut (*Amphericarpa bracteata* L.)) were predominant by relative cover and frequency at all sites. More than 60 percent occurred in fewer than 10 percent of all plots each year. For details, see Grabner (2000b).

Significant treatment effects were detected for species richness ($p < 0.01$). Species richness decreased by 3.0 species in NHM sites, while increasing by 2.8 and 2.5 species in EAM and UAM, respectively. Cover in treated sites (EAM sites 6.1 percent, UAM sites 6.6 percent) increased slightly compared to the NHM sites (2.7 percent), but not by a statistically significant amount ($p = 0.20$).

At least marginally significant treatment effects were also observed for relative cover of annuals/biennials ($p = 0.06$), woody vines ($p = 0.04$), and legumes ($p < 0.01$). The greatest increases in relative cover of annuals/biennials and woody vines were observed in EAM sites. Relative cover of legumes decreased in EAM and UAM sites, but increased slightly in NHM sites. No significant treatment effects were observed for relative cover of non-leguminous forbs ($p = 0.26$), graminoids ($p = 0.15$), shrubs ($p = 0.17$), and small tree seedlings ($p = 0.17$).

Treatment Effects Within Sites (Stand-Level Analyses)

Species richness and cover increased significantly (both $p < 0.001$) following harvest along a gradient of harvest intensity; the greatest responses occurred in clearcuts, while uncut stands showed relatively little change (fig. 1). Clearcut plots were significantly different from thinned EAM plots, plots with group selection and single-tree selection, as well as from uncut plots. UAM plots responded intermediately between clearcut and uncut plots, but similarly to thinned plots. Species richness in group selection plots increased significantly more than in single-tree selection plots.

With the exception of shrubs, clearcut plots were significantly different from uncut plots (all $p < 0.05$, fig. 1). Compared to uncut plots, clearcut plots showed increases

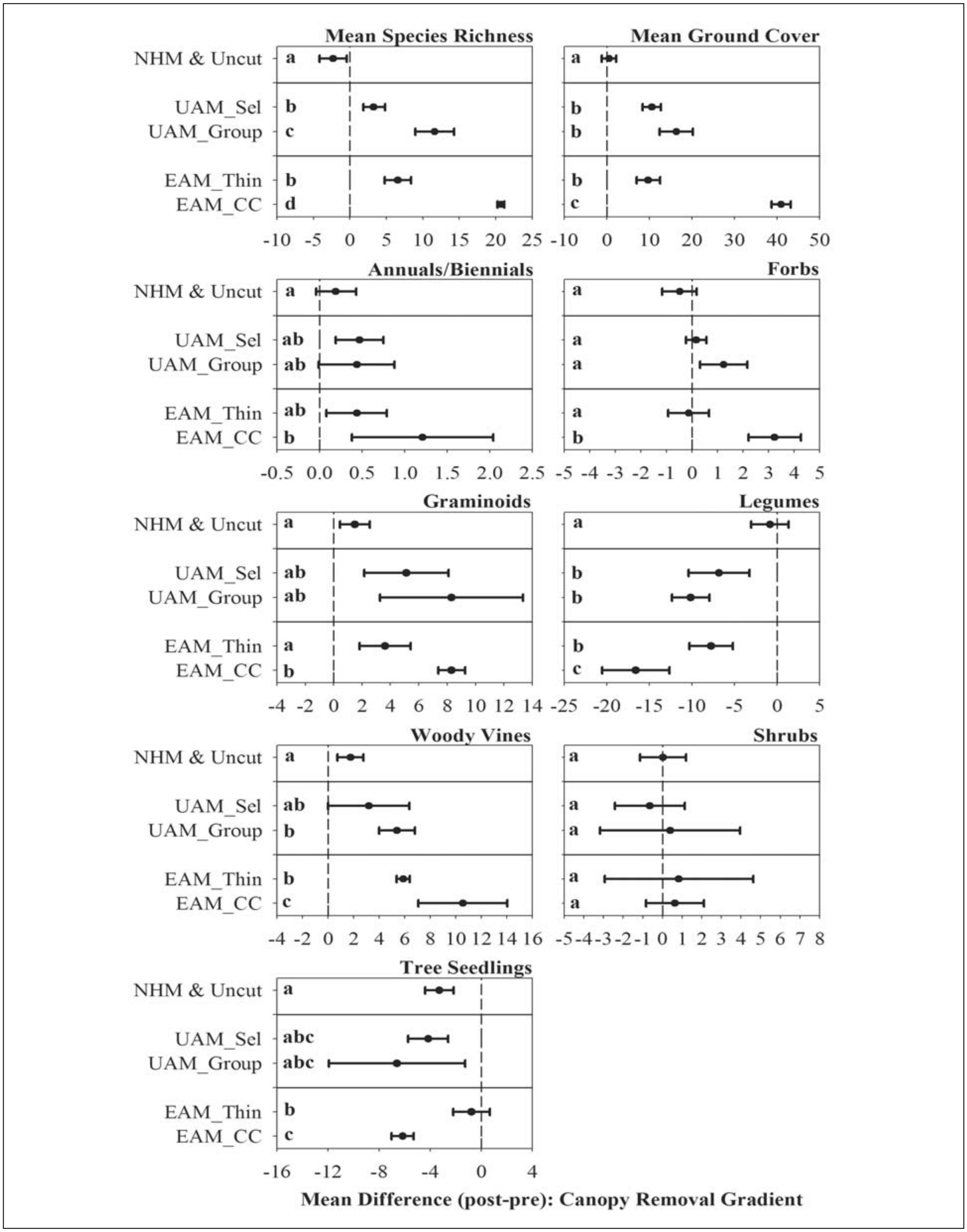

Figure 1—Mean differences between post- and pretreatment values along a harvest intensity gradient. UAM_Sel refers to single-tree selection plots, UAM_Group refers to group selection plots, EAM_Thin refers to thinned plots, EAM_CC refers to plots that were clearcut. Differing letters indicate statistically significant differences among harvest treatments based on Tukey's HSD multiple comparisons test (α = 0.05).

in relative cover of annuals/biennials, forbs, graminoids, and woody vines; clearcuts showed decreases in relative cover of legumes and tree seedlings. Thinned plots generally responded intermediately between clearcut and uncut plots. Only relative cover of legumes and woody vines showed significant differences between thinned and uncut plots. Changes in relative cover of forbs, graminoids, legumes, and tree seedlings were significantly different between thinned and clearcut plots. Only relative cover of legumes differed significantly between single-tree selection plots and uncut plots. Responses were not different between plots with single-tree selection and group selection, although changes in relative cover of legumes and woody vines were significantly more pronounced in plots with group selection compared to uncut plots.

DISCUSSION

Responses to different silvicultural treatments of all ground-layer species combined, and by life-form, were extremely variable. Whereas harvesting induced significant changes in species richness and relative cover of annuals/biennials, forbs, legumes, and woody vines, responses of ground cover and relative covers of shrubs and trees were less straightforward, and no clear relationships to the harvesting gradient emerged at the landscape-level. There are two primary reasons for this outcome. First, no evidence was found that changes due to the harvesting occurred anywhere except in cut plots, and responses in uncut plots within EAM and UAM sites were very similar to those observed in NHM sites (natural background change). Second, with the exception of annuals/biennials, legumes, and woody vines, changes induced by harvesting only a small portion of stands within EAM and UAM sites were too small to result in significant landscape-level changes. This is not to say, however, that harvesting did not result in stand-level changes of relative cover for other life-forms as well. In fact, in most cases the cover of different life-forms changed significantly when clearcut plots were compared to uncut plots.

Responses at the landscape-level largely reflected the magnitude of change induced in the actually treated plots. Stand-level vegetation responses in plots subjected to harvesting often paralleled the gradient of canopy openings induced by different harvesting intensities. For example, species richness tended to increase slightly (though not significantly) in thinned (EAM) and single-tree selection (UAM) plots, and significantly in group opening (UAM) and clearcut (EAM) plots. All harvested plots tended to also increase substantially in mean percentage of total ground cover, with woody vine species such as summer grape (*Vitis aestivalis*) and early successional shrubs such as blackberry (*Rubus pensilvanicus*) contributing in large part to this increase. Annual and biennial species such as fireweed (*Erechtites hieracifolia*), daisy fleabanes (*Erigeron* spp.), and cudweed (*Gnaphalium* spp.), which were essentially absent prior to treatment implementation, exhibited a moderate increase in relative cover in cut plots. Woody vines such as summer grape and Virginia creeper increased in relative cover across most plots, but most noticeably in harvested plots and particularly in clearcuts and plots with group openings. Legumes decreased significantly in relative cover in all harvested plots, while remaining unchanged in most uncut plots. This decrease was primarily due to marked declines in the cover of two very abundant closed-canopy forest species, tick trefoil and hog peanut, which typically occurred in 85 to 95 percent of all pretreatment plots and were always among the top ten species in terms of mean relative pretreatment cover (Grabner et al. 1997). Though not large enough to translate into significant landscape-level changes, mean cover by graminoids such as panic grass (*Panicum boscii*), nut rush (*Scleria triglomerata*), and black-edged sedge (*Carex nigromarginata*) increased in all plots, and particularly in clearcuts and plots with group openings.

Results from this study indicate that different harvesting intensities implemented at the stand-level can result in statistically significant landscape-level changes of the ground-layer vegetation, provided the observed changes are substantial. Statistical significance of treatment effects at the landscape-level can be observed even though treatment effects were spatially confined to the actually treated areas. For example, post- and pretreatment differences between 10 and 30 percent for species richness within even-aged sites were large enough to translate into statistically significant differences at the landscape-level. Are the results of this study, therefore, suggestive of a landscape-level effect, reflecting processes that occurred at larger, landscape-level scales?

After the first round of harvesting, there is no evidence that landscape-level changes in the ground-layer vegetation are more than the sum of stand-level effects. Although dramatic differences were observed at the stand scale along a gradient of no harvest, thinned, single tree, group selection, and clearcut plots, there are no obvious signs that ground-layer vegetation responses were driven by processes that occurred at the landscape-level. That is not to say, however, that landscape-level responses will necessarily continue to be merely scaled-up, (linearly extrapolated) stand-level responses. Our understanding of what controls the rate and direction of vegetation change across spatial scales is currently too incomplete to predict whether or not changes in the composition of the understory will continue to be more or less proportional to the treated area, or if is there a point where those changes become nonlinear. We also do not know if there is a critical level of fragmentation where, due to the combination of habitat loss, invasive species, and dispersal limitation, the recovery and diversity of the ground-layer flora may be compromised. Note that a linear change of the ground flora following harvesting may result in non-linear changes of some fauna and thereby result in landscape-level effects beyond those that may be expected from simple stand-level extrapolation. We contend that future research efforts should be directed at developing predictive modeling approaches that scale stand-level results up to the landscape level. Creative, new statistical designs may be needed to directly address scaling issues and process research within the framework of large-scale studies. Within MOFEP, field observations and experimental analyses must now be combined with the concepts of patch dynamics and hierarchy theory to develop a coherent, spatially explicit, across-scale understanding of forest dynamics that enables the development of scientifically sound management and conservation plans.

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Stand structure in Washington State Capitol Forest 75 years after railroad logging. *Photo by Tom Iraci*

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